Appendix I– Electrical Effects

SCHULTZ - HANFORD AREA
TRANSMISSION LINE PROJECT

APPENDIX I

ELECTRICAL EFFECTS

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Table of Contents

List of Tables

List of Figures

ELECTRICAL EFFECTS FROM THE PROPOSED SCHULTZ – HANFORD AREA TRANSMISSION PROJECT

1.0 Introduction

The Bonneville Power Administration (BPA) is proposing to build a 500-kilovolt (kV) transmission line from the Schultz Substation near Ellensburg, Washington, to either the existing BPA 500-kV Hanford Substation located on the Hanford Site or to a new 500-kV Wautoma Substation located west of the Hanford Site. The proposed line and the associated remodeled and new substations are known as the Schultz – Hanford Area Transmission Project. Alternative routes include construction on new right-of-way on a new corridor, on existing right-of-way parallel to several existing lines, and on new right-of-way parallel to existing 230-kV and/or 115-kV lines. In addition, the existing Sickler-Schultz 500-kV line would be realigned on new right-of-way north of the Schultz substation. The purpose of this report is to describe and quantify the electrical effects of the proposed Schultz – Hanford/Wautoma line. These include the following:

- the levels of 60-hertz (Hz; cycles per second) electric and magnetic fields (EMF) at 3.28 feet (ft.) or 1 meter (m) above the ground,
- the effects associated with those fields,
- the levels of audible noise produced by the line, and
- electromagnetic interference associated with the line.

Electrical effects occur near all transmission lines, including those already present along segments of the proposed route for the Schultz - Hanford/Wautoma line. Therefore, the levels of these quantities for the proposed line are computed and compared with those from the existing lines.

The voltage on the conductors of transmission lines generates an electric field in the space between the conductors and the ground. The electric field is calculated or measured in units of volts-per-meter (V/m) or kilovolts-per-meter (kV/m) at a height of 3.28 feet (ft.) (1 meter [m]) above the ground. The current flowing in the conductors of the transmission line generates a magnetic field in the air and earth near the transmission line; current is expressed in units of amperes (A). The magnetic field is expressed in milligauss (mG), and is usually measured or calculated at a height of 3.28 ft. (1 m) above the ground. The electric field at the surface of the conductors causes the phenomenon of corona. Corona is the electrical breakdown or ionization of air in very strong electric fields, and is the source of audible noise, electromagnetic radiation, and visible light.

To quantify EMF levels along the route, the electric and magnetic fields from the proposed and existing lines were calculated using the BPA Corona and Field Effects Program (USDOE, undated). In this program, the calculation of 60-Hz fields uses standard superposition techniques for vector fields from several line sources: in this case, the line sources are transmission-line conductors. (Vector fields have both magnitude and direction: these must be taken into account when combining fields from different sources.) Important input parameters to the computer program are voltage, current, and geometric configuration of the line. The transmission-line conductors are assumed to be straight, parallel to each other, and located above and parallel to an infinite flat ground plane. Although such conditions do not occur under real lines because of conductor sag and variable terrain, the validity and limitations of calculations using these assumptions have been well verified by comparisons with measurements. This approach was used to estimate fields for the proposed Schultz - Hanford/Wautoma line, where minimum clearances were assumed to provide worst-case (highest) estimates for the fields.

Electric fields are calculated using an imaging method. Fields from the conductors and their images in the ground plane are superimposed with the proper magnitude and phase to produce the total field at a selected location.

The total magnetic field is calculated from the vector summation of the fields from currents in all the transmission-line conductors. Balanced currents are assumed; the contribution of image currents in the conductive earth is not included. Peak currents and power flow directions for the proposed and existing lines were provided by BPA and are based on the projected summer peak power loads in 2006. In the case of corridors with more than one line, calculations were performed for similar (maximum) current conditions on both lines.

Electric and magnetic fields for the proposed line were calculated at the standard height (3.28 ft. or 1 m) above the ground (IEEE, 1987). Calculations were performed out to 300 ft. (91 m) from the centerline of the proposed line and out to 200 ft. (61 m) from the centerline of existing lines. The validity and limitations of such calculations have been well verified by measurements. Because maximum voltage, maximum current, and minimum conductor height above-ground are used, ***the calculated values given here represent worst-case conditions:*** i.e., the calculated fields are higher than they would be in practice. Such worst-case conditions would seldom occur.

The corona performance of the proposed line was also predicted using the BPA Corona and Field Effects Program (USDOE, undated). Corona performance is calculated using empirical equations that have been developed over several years from the results of measurements on numerous high-voltage lines (Chartier and Stearns, 1981; Chartier, 1983). The validity of this approach for corona-generated audible noise has been demonstrated through comparisons with measurements on other lines all over the United States (IEEE Committee Report, 1982). The accuracy of this method for predicting corona-generated radio and television interference from transmission lines has also been established (Olsen et al., 1992). Of the methods available for predicting radio interference levels, the BPA empirical equivalent method agrees most closely with long-term data. Important input parameters to the computer program are voltage, current, conductor size, and geometric configuration of the line.

Corona is a highly variable phenomenon that depends on conditions along a length of line. Predictions of the levels of corona effects are reported in statistical terms to account for this variability. Calculations of audible noise and electromagnetic interference levels were made under conditions of an estimated average operating voltage (540 kV for the proposed line) and with the average line height (47 ft. or 14 m for 500-kV lines). Levels of audible noise, radio interference, and television interference are predicted for both fair and foul weather; however, corona is basically a foul-weather phenomenon. Wet conductors can occur during periods of rain, fog, snow, or icing. Along the alternative routes of the proposed Schultz – Hanford/Wautoma transmission line, such conditions are expected to occur about 7 percent of the time during a year, based on hourly records at the Yakima Air Terminal from 1996 to 1999. Corona activity also increases with altitude. For purposes of evaluating corona effects from the proposed line, an altitude of 2000 ft. (610 m) was assumed for Configurations A-1 to A-4 and 1200 ft. (366 m) for Configurations D-1 to D-4.

2.0 Physical Description

2.1 Proposed Line

The Schultz – Hanford/Wautoma line would be a three-phase, single-circuit design with a maximum phase-to-phase voltage of 550 kV. The average voltage of the line would be 540 kV. The maximum electrical current on the line would be 1436 A. The estimated currents in each phase are based on the projected summer peak load in 2006, as determined in case studies prepared by BPA. BPA provided the physical and operating characteristics of the proposed and existing lines.

The physical dimensions and electrical characteristics for the configuration of the proposed line are shown in Figure 1, and summarized in Table 1. The three 1.302-inch (in.) (3.31-centimeter (cm)) diameter conductors for each phase (ACSR: steel reinforced aluminum conductors) would be arranged in an inverted triangle bundle configuration with 17-in. (43.3-cm) spacing between conductors. Voltage and current waves are displaced by 120° in time (one-third of a cycle) on each electrical phase. The conductor bundles would be arranged in a delta or triangular configuration on steel towers, as shown in Figure 1. The horizontal phase spacing between the lower conductor bundles would be 40 ft. (12.2 m). The vertical spacing between the upper and lower conductor bundles would be 28.7 ft. (8.8 m). Minimum conductor-to-ground clearance would be 33 ft. (10.1 m) at a conductor temperature of 122°F (50°C), which represents maximum operating conditions and high ambient air temperatures; clearances above ground would be greater under normal operating temperatures. The average clearance above ground will be approximately 47 ft. (14.3 m); this value was used for corona calculations. At road crossings, the ground clearance would be at least 54 ft. (116.5 m) at 122°F (50°C). The 33-ft. (10.1-m) minimum clearance provided by BPA is greater than the minimum distance of the conductors above ground required to meet the National Electric Safety Code (NESC) (IEEE, 1990). The final design of the proposed line could entail larger clearances. The right-of-way width for the proposed line would be 150 ft. (45.7 m).

2.2 Existing Lines

The proposed Schultz – Hanford/Wautoma 500-kV line could parallel existing BPA 500-kV, 230-kV, and 115-kV lines along different segments of the alternative routes. In addition, the realigned Sickler-Schultz 500-kV line could parallel and existing 345-kV line. Eight possible configurations were identified, including the new right-of-way with no parallel line (Table 2). The physical and electrical characteristics of the corridor configurations that were analyzed are given in Table 1; cross-sections of the corridors are shown in Figure 1.

3.0 Electric Field

3.1 Basic Concepts

An electric field is said to exist in a region of space if an electrical charge, at rest in that space, experiences a force of electrical origin (i.e., electric fields cause free charges to move). Electric field is a vector quantity: that is, it has both magnitude and direction. The direction corresponds to the direction that a positive charge would move in the field. Sources of electric fields are unbalanced electrical charges (positive or negative) and time-varying magnetic fields. Transmission lines, distribution lines, house wiring, and appliances generate electric fields in their vicinity because of unbalanced electrical charge on energized conductors. The unbalanced charge is associated with the voltage on the energized system. On the power system in North America, the voltage and charge on the energized conductors are cyclic (plus to minus to plus) at a rate of 60 times per second. This changing voltage results in electric fields near sources that are also time-varying at a frequency of 60 Hz (a frequency unit equivalent to cycles per second).

As noted earlier, electric fields are expressed in units of volts per meter (V/m) or kilovolts (thousands of volts) per meter (kV/m). Electric- and magnetic-field magnitudes in this report are expressed in root-mean-square (rms) units. For sinusoidal waves, the rms amplitude is given as the peak amplitude divided by the square root of two.

The spatial uniformity of an electric field depends on the source of the field and the distance from that source. On the ground, under a transmission line, the electric field is nearly constant in magnitude and direction over distances of several feet (1 meter). However, close to transmission- or distribution-line conductors, the field decreases rapidly with distance from the conductors. Similarly, near small sources such as appliances, the field is not uniform and falls off even more rapidly with distance from the device. If an energized conductor (source) is inside a grounded conducting enclosure, then the electric field outside the enclosure is zero, and the source is said to be shielded.

Electric fields interact with the charges in all matter, including living systems. When a conducting object, such as a vehicle or person, is located in a time-varying electric field near a transmission line, the external electric fields exert forces on the charges in the object, and electric fields and currents are induced in the object. If the object is grounded, then the total current induced in the body (the "short-circuit current") flows to earth. The distribution of the currents within, say, the human body, depends on the electrical conductivities of various parts of the body: for example, muscle and blood have higher conductivity than bone and would therefore experience higher currents.

At the boundary surface between air and the conducting object, the field in the air and perpendicular to the conductor surface is much, much larger than the field in the conductor itself. For example, the average surface field on a human standing in a 10 kV/m field is 27 kV/m; the internal fields in the body are much smaller: approximately 0.008 V/m in the torso and 0.45 V/m in the ankles.

3.2 Transmission-line Electric Fields

The electric field created by a high-voltage transmission line extends from the energized conductors to other conducting objects such as the ground, towers, vegetation, buildings, vehicles, and people. The calculated strength of the electric field at a height of 3.28 ft. (1 m) above an unvegetated, flat earth is frequently used to describe the electric field under straight parallel transmission lines. The most important transmission-line parameters that determine the electric field at a 1-m height are conductor height above ground and line voltage.

Calculations of electric fields from transmission lines are performed with computer programs based on well-known physical principles (cf., Deno and Zaffanella, 1982). The calculated values under these conditions represent an ideal situation. When practical conditions approach this ideal model, measurements and calculations agree. Often, however, conditions are far from ideal because of variable terrain and vegetation. In these cases, fields are calculated for ideal conditions, with the lowest conductor clearances to provide upper bounds on the electric field under the transmission lines. With the use of more complex models or empirical results, it is also possible to account accurately for variations in conductor height, topography, and changes in line direction. Because the fields from different sources add vectorially, it is possible to compute the fields from several different lines if the electrical and geometrical properties of the lines are known. However, in general, electric fields near transmission lines with vegetation below are highly complex and cannot be calculated. Measured fields in such situations are highly variable.

For evaluation of EMF from transmission lines, the fields must be calculated for a specific line condition. The NESC states the condition for evaluating electric-field-induced short-circuit current for lines with voltage above 98 kV, line-to-ground, as follows: conductors are at a minimum clearance from ground corresponding to a conductor temperature of 120°F (49°C), and at a maximum voltage (IEEE, 1990). BPA has supplied the needed information for calculating electric and magnetic fields from the proposed transmission lines: the maximum operating voltage, the estimated peak current in 2006, and the minimum conductor clearances.

There are standard techniques for measuring transmission-line electric fields (IEEE, 1987). Provided that the conditions at a measurement site closely approximate those of the ideal situation assumed for calculations, measurements of electric fields agree well with the calculated values. If the ideal conditions are not approximated, the measured field can differ substantially from calculated values. Usually the actual electric field at ground level is reduced from the calculated values by various common objects that act as shields.

Maximum or peak field values occur over a small area at midspan, where conductors are closest to the ground. As the location of an electric-field profile approaches a tower, the conductor clearance increases, and the peak field decreases. A grounded tower will reduce the electric field considerably by shielding. For the parallel line configurations considered here, minimum conductor clearances were assumed to occur along the same lateral profile for both lines. This condition will not necessarily occur in practice, because the towers for the parallel lines may be offset or located at different elevations. The assumption of simultaneous minimum clearance results in peak fields that may be larger than what occurs in practice.

For traditional transmission lines, such as the proposed line, where the right-of-way extends laterally well beyond the conductors, electric fields at the edge of the right-of-way are not as sensitive as the peak field to conductor height. Computed values at the edge of the right-of-way for any line height are fairly representative of what can be expected all along the transmission-line corridor. However, the presence of vegetation on and at the edge of the right-of-way will reduce actual electric-field levels below calculated values.

3.3 Calculated Values of Electric Fields

Table 3 shows the calculated values of electric field at 3.28 ft. (1 m) above ground for the proposed Schultz - Hanford/Wautoma 500-kV transmission-line configurations. The peak value on the right-of-way and the value at the edge of the right-of-way are given for the eight proposed corridor configurations and for minimum and average conductor clearances. Figure 2a shows lateral profiles for the electric field from the proposed line for the minimum and average line heights. Figures 2b–c show calculated fields for both existing and proposed Configurations D-1 and D-3 with parallel lines.

The calculated peak electric field expected on the right-of-way of the proposed line on new right-of-way (Configuration A-1) is 8.9 kV/m. When the proposed line parallels other lines the peak field under the proposed line is 8.9 kV/m or less.

As shown in Figure 2a, the peak values would be present only at locations directly under the line, near mid-span, where the conductors are at the minimum clearance. The conditions of minimum conductor clearance at maximum current and maximum voltage occur very infrequently. The calculated peak levels are rarely reached under real-life conditions, because the actual line height is generally above the minimum value used in the computer model, because the actual voltage is below the maximum value used in the model, and because vegetation within and near the edge of the right-of-way tends to shield the field at ground level. Maximum electric fields under the existing parallel 500-kV, 230-kV, and 115-kV lines are 9.7, 3.3, and 1.7 kV/m, respectively.

The largest values expected at the edge of the right-of-way nearest the proposed line would be 2.0 kV/m. On the edge of the right-of-way away from the proposed line, the field would vary with the line configuration present. The largest fields at the edges of the existing rights-of-way are 5.2 and 2.0 kV/m for the 500- and 230-kV lines, respectively.

3.4 Environmental Electric Fields

The electric fields associated with the Schultz - Hanford/Wautoma line can be compared with those found in other environments. Sources of 60-Hz electric (and magnetic) fields exist everywhere electricity is used; levels of these fields in the modern environment vary over a wide range. Electric-field levels associated with the use of electrical energy are orders of magnitude greater than the naturally occurring 60-Hz fields of about 0.0001 V/m, which stem from atmospheric and extraterrestrial sources.

Electric fields in outdoor, publicly accessible places range from less than 1 V/m to 12 kV/m; the large fields exist close to high-voltage transmission lines of 500 kV or higher. In remote areas without electrical service, 60-Hz field levels can be much lower than 1 V/m. Electric fields in home and work environments generally are not spatially uniform like those of transmission lines; therefore, care must be taken when making comparisons between fields from different sources such as appliances and electric lines. In addition, fields from all sources can be strongly modified by the presence of conducting objects. However, it is helpful to know the levels of electric fields generated in domestic and office environments in order to compare commonly experienced field levels with those near transmission lines.

Numerous measurements of residential electric fields have been reported for various parts of the United States, Canada, and Europe. Although there have been no large studies of residential electric fields, sufficient data are available to indicate field levels and characteristics. Measurements of domestic 60-Hz electric fields indicate that levels are highly variable and source-dependent. Electric-field levels are not easily predicted because walls and other objects act as shields, because conducting objects perturb the field, and because homes contain numerous localized sources. Internal sources (wiring, fixtures, and appliances) seem to predominate in producing electric fields inside houses. Average measured electric fields in residences are generally in the range of 5 to 20 V/m. In a large occupational exposure monitoring project that included electric-field measurements at homes, average exposures for all groups away from work were generally less than 10 V/m (Bracken, 1990).

Electric fields from household appliances are localized and decrease rapidly with distance from the source. Local electric fields measured at 1 ft. (0.3 m) from small household appliances are typically in the range of 30 to 60 V/m. Stopps and Janischewskyj (1979) reported electric-field measurements near 20 different appliances; at a 1-ft. (0.3-m) distance, fields ranged from 1 to 150 V/m, with a mean of 33 V/m. In another survey, reported by Deno and Zaffanella (1982), field measurements at a 1-ft. (0.3-m) distance from common domestic and workshop sources were found to range from 3 to 70 V/m.

The localized fields from appliances are not uniform, and care should be taken in comparing them with transmission-line fields.

Electric blankets can generate higher localized electric fields. Sheppard and Eisenbud (1977) reported fields of 250 V/m at a distance of approximately 1 ft. (0.3 m). Florig et al. (1987) carried out extensive empirical and theoretical analysis of electric-field exposure from electric blankets and presented results in terms of uniform equivalent fields such as those near transmission lines. Depending on what parameter was chosen to represent intensity of exposure and the grounding status of the subject, the equivalent vertical 60-Hz electric-field exposure ranged from 20 to over 3500 V/m. The largest equivalent field corresponds to the measured field on the chest, with the blanket-user grounded. The average field on the chest of an ungrounded blanket-user yields an equivalent vertical field of 960 V/m. As manufacturers have become aware of the controversy surrounding EMF exposures, electric blankets have been redesigned to reduce magnetic fields. However, electric fields from these "low field" blankets are still comparable with those from older designs (Bassen et al., 1991).

Generally, people in occupations not directly related to high-voltage equipment are exposed to electric fields comparable with those of residential exposures. For example, the average electric field measured in 14 commercial and retail locations in rural Wisconsin and Michigan was 4.8 V/m (ITT Research Institute, 1984). Median electric field was about 3.4 V/m. These values are about one-third the values in residences reported in the same study. Power-frequency electric fields near video display terminals (VTDs) are about 10 V/m, similar to those of other appliances (Harvey, 1983). Electric-field levels in public buildings such as shops, offices, and malls appear to be comparable with levels in residences.

Using a small 60-Hz dosimeter, Deadman et al. (1988) measured occupational exposures over a one-week period for 20 utility workers and 16 office workers. The geometric mean of the weekly electric-field exposures during work for the 20 utility workers was 48.3 V/m, compared to 4.9 V/m for the office workers. The transmission linemen (n=2, 420 V/m) had the highest geometric mean exposures. These results are consistent with previous studies that used less sophisticated instrumentation.

In a survey of 1,882 volunteers from utilities, electric-field exposures were measured for 2,082 workdays and 657 non-work days (Bracken, 1990). Electric-field exposures for occupations other than those directly related to high-voltage equipment were equivalent to those for non-work exposure.

Thus, except for the relatively few occupations where high-voltage sources are prevalent, electric fields encountered in the workplace are probably similar to those of residential exposures. Even in electric utility occupations where high field sources are present, exposures to high fields are limited on average to minutes per day.

Electric fields found in publicly accessible areas near high-voltage transmission lines can typically range up to 3 kV/m for 230-kV lines, to 10 kV/m for 500-kV lines, and to 12 kV/m for 765-kV lines. Although these peak levels are considerably higher than the levels found in other public areas, they are present only in limited areas on rights-of-way.

The calculated electric fields for the proposed Schultz - Hanford/Wautoma 500-kV transmission line are consistent with the levels reported for other 500-kV transmission lines in Washington and elsewhere. The calculated electric fields on the right-of-way of the proposed transmission line would be much higher than levels normally encountered in residences and offices.

4.0 Magnetic Field

4.1 Basic Concepts

Magnetic fields can be characterized by the force they exert on a moving charge or on an electrical current. As with the electric field, the magnetic field is a vector quantity characterized by both magnitude and direction. Electrical currents generate magnetic fields. In the case of transmission lines, distribution lines, house wiring, and appliances, the 60-Hz electric current flowing in the conductors generates a time-varying, 60-Hz magnetic field in the vicinity of these sources. The strength of a magnetic field is measured in terms of magnetic lines of force per unit area, or magnetic flux density. The term "magnetic field," as used here, is synonymous with magnetic flux density and is expressed in units of Gauss (G) or milligauss (mG).

The uniformity of a magnetic field depends on the nature and proximity of the source, just as the uniformity of an electric field does. Transmission-line-generated magnetic fields are quite uniform over horizontal and vertical distances of several feet near the ground. However, for small sources such as appliances, the magnetic field decreases rapidly over distances comparable with the size of the device.

The interaction of a time-varying magnetic field with conducting objects results in induced electric field and currents in the object. A changing magnetic field through an area generates a voltage around any conducting loop enclosing the area (Faraday's law). This is the physical basis for the operation of an electrical transformer. For a time-varying sinusoidal magnetic field, the magnitude of the induced voltage around the loop is proportional to the area of the loop, the frequency of the field, and the magnitude of the field. The induced voltage around the loop results in an induced electric field and current flow in the loop material. The induced current that flows in the loop depends on the conductivity of the loop.

4.2 Transmission-line Magnetic Fields

The magnetic field generated by currents on transmission-line conductors extends from the conductors through the air and into the ground. The magnitude of the field at a height of 3.28 ft. (1 m) is frequently used to describe the magnetic field under transmission lines. Because the magnetic field is not affected by non-ferrous materials, the field is not influenced by normal objects on the ground under the line. The direction of the maximum field varies with location. (The electric field, by contrast, is essentially vertical near the ground.) The most important transmission-line parameters that determine the magnetic field at 3.28 ft. (1 m) height are conductor height above ground and magnitude of the currents flowing in the conductors. As distance from the transmission-line conductors increases, the magnetic field decreases.

Calculations of magnetic fields from transmission lines are performed using well-known physical principles (cf., Deno and Zaffanella, 1982). The calculated values usually represent the ideal straight parallel-conductor configuration. For simplicity, a flat earth is usually assumed. Balanced currents (currents of the same magnitude for each phase) are also assumed. This is usually valid for transmission lines, where loads on all three phases are maintained in balance during operation. Induced image currents in the earth are usually ignored for calculations of magnetic field under or near the right-of-way. The resulting error is negligible. Only at distances greater than 300 ft. (91 m) from a line do such contributions become significant (Deno and Zaffanella, 1982). The clearance for magnetic-field calculations for the proposed line was the same as that used for electric-field evaluations.

Standard techniques for measuring magnetic fields near transmission lines are described in ANSI IEEE Standard No. 644-1987 (1987). Measured magnetic fields agree well with calculated values, provided the currents and line heights that go into the calculation correspond to the actual values for the line. To realize such agreement, it is necessary to get accurate current readings during field measurements (because currents on transmission lines can vary considerably over short periods of time) and also to account for all field sources in the vicinity of the measurements.

As with electric fields, the maximum or peak magnetic fields occur in areas near the centerline and at midspan where the conductors are the lowest. If more than one line is present, the peak field will depend on the relative electrical phasing of the conductors. The magnetic field at the edge of the right-of-way is not very dependent on line height. If more than one line is present, the peak field can depend on the relative electrical phasing of the conductors and the direction of power flow. Phasing information was available for the parallel 500-kV line, but not for the parallel 115-kV line. Assumption of a phasing scheme for the 115-kV line does not affect the calculated field levels on the existing or proposed corridor.

4.3 Calculated Values for Magnetic Fields

Table 4 gives the calculated values of the magnetic field at 3.28 ft. (1 m) height for the proposed 500-kV transmission-line configurations. Field values on the right-of-way and at the edge of the right-of-way are given for projected maximum currents during summer peak load in 2006, for minimum and average conductor clearances. The actual magnetic-field levels would vary, as currents on the lines change daily and seasonally and as ambient temperature changes. Average currents over the year would be about 45 percent of the maximum values. Average fields over a year would be considerably reduced from the peak values, as a result of increased clearances above the minimum height and reduced currents from the maximum summer load value.

Figure 3 shows lateral profiles of the magnetic field under maximum current and minimum clearance conditions for selected configurations of the proposed 500-kV transmission line. A field profile for average height under Configuration A-1 is included in Figure 3a. Maximum field levels for the proposed and existing configurations of Configurations D-1 and D-3 are shown in Figures 3b and 3c.

For the proposed 500-kV line on new right-of-way with no parallel lines (Configuration A-1), the maximum calculated 60-Hz magnetic field expected at 3.28 ft. (1 m) above ground is 244 mG. This field is calculated for the maximum current of 1436 A, with the conductors at a height of 33 ft. (9.1 m). The maximum field would decrease for increased conductor clearance. For an average conductor height over a span of 47 ft. (14.3 m), the maximum field would be 137 mG. (See Figure 3a.) Maximum fields under the proposed line in the configurations with parallel lines would be less than these values.

At the edge of the right-of-way of the proposed line, the calculated magnetic field for maximum current conditions is 55 mG for minimum conductor height and 46 mG for average conductor height. Fields at the edge of the right-of-way of the proposed line in the configurations with parallel lines would be less than those for Configuration A-1. The field at the edge of the right-of-way adjacent to a parallel line would depend on that line.

The magnetic field falls off rapidly as distance from the line increases. The calculated magnetic field for maximum current would be less than 10 mG at about 185 ft. (72 m) from the centerline. At a distance of 200 ft. (61 m) from the centerline of the proposed line, the field would be 8 mG for maximum current conditions.

The calculated fields for the seven other configurations that were analyzed are given in Table 4. For the existing lines, the peak magnetic fields on the rights-of-way are 302 mG and 170 mG, for the 500-kV and 230-kV lines, respectively. Fields at the edges of the existing rights-of-way range from 158 mG for the Vantage-Schultz 500-kV line to 7 mG for the North Bonneville-Midway 230-kV line, which has a very wide right-of-way. The maximum and edge of right-of-way field levels for the realigned Sickler-Schultz 500-kV line (Configurations A-2 and A-3) would be 262 mG and 60 mG, respectively.

4.4 Environmental Magnetic Fields

Transmission lines are not the only source of magnetic fields; as with 60-Hz electric fields, 60-Hz magnetic fields are present throughout the environment of a society that relies on electricity as a principal energy source. The magnetic fields associated with the proposed Schultz - Hanford/Wautoma 500-kV line can be compared with fields from other sources. The range of 60-Hz magnetic-field exposures in publicly accessible locations such as open spaces, transmission-line rights-of-way, streets, pedestrian walkways, parks, shopping malls, parking lots, shops, hotels, public transportation, and so on range from less than 0.1 mG to about 1 G, with the highest values occurring near small appliances with electric motors. In occupational settings in electric utilities, where high currents are present, magnetic-field exposures for workers can be above 1 G. At 60 Hz, the magnitude of the natural magnetic field is approximately 0.0005 mG.

Several investigations of residential fields have been conducted. Short-term measurements of magnetic fields in 483 residences in the Denver area resulted in mean fields of 0.76 mG (Standard Deviation (SD) = 0.79 mG) under low-power conditions: with all appliances and lights off (Savitz, 1987). Approximately six percent of the low-power residences had fields greater than 2.5 mG. The high-power (appliances and lights on) mean fields for 481 residences were 1.05 mG (SD = 1.3 mG) (Savitz, 1987). The average low-power magnetic field for the 133 residences with buried-cable electrical service in the study was 0.49 mG (SD = 0.53 mG).

Kaune et al. (1987) reported on 24-hour magnetic-field measurements made in 43 residences in the Seattle area. The mean for these measurements was 1.0 mG (median = 0.6 mG; SD = 1.2 mG). The magnetic-field data demonstrated a diurnal variation that coincided with utility loads: peak values at 8 am and 6-7 pm, and minimum values very early in the morning. No correlation of magnetic field with individual power consumption in a house was observed. The Denver and Seattle studies both concluded that the predominant sources of residential magnetic fields were external to the home (e.g., transmission and distribution lines). The studies also identified ground-return currents in residences as a possible important source of residential magnetic fields.

In a large study to identify and quantify significant sources of 60-Hz magnetic fields in residences, measurements were made in 996 houses, randomly selected throughout the country (Zaffanella, 1993). The most common sources of residential fields were power lines, the grounding system of residences, and appliances. Field levels were characterized by both point-in-time (spot) measurements and 24-hour measurements. Spot measurements averaged over all rooms in a house exceeded 0.6 mG in 50 percent of the houses and 2.9 mG in 5 percent of houses. Power lines generally produced the largest average fields in a house over a 24-hour period. On the other hand, grounding system currents proved to be a more significant source of the highest fields in a house. Appliances were found to produce the highest local fields; however, fields fell off rapidly with increased distance. For example, the median field near microwave ovens was 36.9 mG at a distance of 10.5 in (0.27 m) and 2.1 mG at 46 in (1.17 m). Across the entire sample of 996 houses, higher magnetic fields were found in, among others, urban areas (vs.

rural); multi-unit dwellings (vs. single-family); old houses (vs. new); and houses with grounding to a municipal water system.

In an extensive measurement project to characterize the magnetic-field exposure of the general population, over 1000 randomly selected persons in the United States wore a personal exposure meter for 24 hours and recorded their location in a simple diary (Zaffanella and Kalton, 1998). Based on the measurements of 853 persons, the estimated 24-hour average exposure for the general population is 1.24 mG and the estimated median exposure is 0.88 mG. The average field "at home, not in bed" is 1.27 mG and "at home, in bed" is 1.11 mG. Average personal exposures were found to be largest "at work" (mean of 1.79 mG and median of 1.01 mG) and lowest "at home, in bed" (mean of 1.11 mG and median of 0.49 mG). Average fields in school were also low (mean of 0.88 mG and median of 0.69 mG). Factors associated with higher exposures at home were smaller residences, duplexes and apartments, metallic rather than plastic water pipes, and nearby overhead distribution lines.

As noted above, magnetic fields from appliances are localized and decrease rapidly with distance from the source. Localized 60-Hz magnetic fields have been measured near about 100 household appliances such as ranges, refrigerators, electric drills, food mixers, and shavers (Gauger, 1985). At a distance of 1 ft. (0.3 m), the maximum magnetic field ranged from 0.3 to 270 mG, with 95 percent of the measurements below 100 mG. Ninety-five percent of the levels at a distance of 4.9 ft. (1.5 m) were less than 1 mG. Devices that use light-weight, high-torque motors with little magnetic shielding exhibited the largest fields. These included vacuum cleaners and small hand-held appliances and tools. Microwave ovens with large power transformers also exhibited relatively large fields. Electric blankets have been a much-studied source of magnetic-field exposure because of the length of time they are used and because of the close proximity to the body. Florig and Hoburg (1988) estimated that the average magnetic field in a person using an electric blanket was 15 mG, and that the maximum field could be 100 mG. New "low-field" blankets have magnetic fields at least 10 times lower than those from conventional blankets (Bassen et al., 1991).

In a domestic magnetic-field survey, Silva et al. (1989) measured fields near different appliances at locations typifying normal use (e.g., sitting at a typewriter or standing at a stove). Specific appliances with relatively large fields included can openers ($n = 9$), with typical fields ranging from 30 to 225 mG and a maximum value up to 2.7 G; shavers ($n = 4$), with typical fields from 50 to 300 mG and maximum fields up to 6.9 G; and electric drills ($n = 2$), with typical fields from 56 to 190 mG and maximum fields up to 1.5 G. The fields from such appliances fall off very rapidly with distance and are present only for short periods. Thus, although instantaneous magnetic-field levels close to small hand-held appliances can be quite large, they do not contribute to average area levels in residences.

Although studies of residential magnetic fields have not all considered the same independent parameters, the following consistent characterization of residential magnetic fields emerges from the data:

(1) External sources play a large role in determining residential magnetic-field levels. Transmission lines, when nearby, are an important external source. Unbalanced ground currents on neutral conductors and other conductors, such as water pipes in and near a house, can represent a significant source of magnetic field. Distribution lines per se, unless they are quite close to a residence, do not appear to be a traditional distance-dependent source.

(2) Homes with overhead electrical service appear to have higher average fields than those with underground service.

(3) Appliances represent a localized source of magnetic fields that can be much higher than average or area fields. However, fields from appliances approach area levels at distances greater than 3 ft. (1 m) from the device.

Although important variables in determining residential magnetic fields have been identified, quantification and modeling of their influence on fields at specific locations is not yet possible. However, a general characterization of residential magnetic-field level is possible: average levels in the United States are in the range of 0.5 to 1.0 mG, with the average field in a small number of homes exceeding this range by as much as a factor of 10 or more. Average personal exposure levels are slightly higher, possibly due to use of appliances and varying distances to other sources. Maximum fields can be much higher.

Magnetic fields in commercial and retail locations are comparable with those in residences. As with appliances, certain equipment or machines can be a local source of higher magnetic fields. Utility workers who work close to transformers, generators, cables, transmission lines, and distribution systems clearly experience high-level fields. Other sources of fields in the workplace include motors, welding machines, computers, and VDTs. In publicly accessible indoor areas, such as offices and stores, field levels are generally comparable with residential levels, unless a high-current source is nearby.

Because high-current sources of magnetic field are more prevalent than high-voltage sources, occupational environments with relatively high magnetic fields encompass a more diverse set of occupations than do those with high electric fields. For example, in occupational magnetic-field measurements reported by Bowman et al. (1988), the geometric mean field from 105 measurements of magnetic field in "electrical worker" job locations was 5.0 mG. "Electrical worker" environments showed the following elevated magnetic-field levels (geometric mean greater than 20 mG): industrial power supplies, alternating current (ac) welding machines, and sputtering systems for electronic assembly. For secretaries in the same study, the geometric mean field was 3.1 mG for those using VDTs (n = 6) and 1.1 mG for those not using VDTs (n = 3).

In a Canadian study, the geometric mean of the time-weighted average field for the weekly work exposure of 20 utility workers was 16.6 mG, compared to 1.6 mG for 16 office workers (Deadman et al., 1988). The geometric mean field for the office environment was comparable to that observed during non-work periods for office workers and comparable to that for both groups during sleep (when the exposure meter was not worn).

Measurements of personal exposure to magnetic fields were made for 1,882 volunteer utility workers for a total of 4,411 workdays (Bracken, 1990). Median workday mean exposures ranged from 0.5 mG for clerical workers without computers to 7.2 mG for substation operators. Occupations not specifically associated with transmission and distribution facilities had median workday exposures less than 1.5 mG, while those associated with such facilities had median exposures above 2.3 mG. Magnetic-field exposures measured in homes during this study were comparable with those recorded in offices.

Magnetic fields in publicly accessible outdoor areas seem to be, as expected, directly related to proximity to electric-power transmission and distribution facilities. Near such facilities, magnetic fields are generally higher than indoors (residential). Higher-voltage facilities tend to have higher fields. Typical maximum magnetic fields in publicly accessible areas near transmission facilities can range from less than a few milligauss up to 300 mG or more, near heavily loaded lines operated at 230 to 765 kV. The levels depend on the line load, conductor height, and location on the right-of-way. Because magnetic fields near high-voltage transmission lines depend on the current in the line, they can vary daily and seasonally. To characterize fields from the distribution system, Heroux (1987) measured 60-Hz magnetic fields with a mobile platform along 140 mi. (223 km) of roads in Montreal. The median field level averaged over nine different routes was 1.6 mG, with 90 percent of the measurements less than about 5.1 mG. Spot measurements indicated that typical fields directly above underground distribution systems were 5 to 19 mG. Beneath overhead distribution lines, typical fields were 1.5 to 5 mG on the primary side of the transformer, and 4 to 10 mG on the secondary side. At the surface of distribution poles, the magnetic field ranged from 10 to 100 mG, depending on structure type. Near ground-based transformers used in residential areas, fields were 80 to 1000 mG at the surface and 10 to 100 mG at a distance of 1 ft. (0.3 m).

The magnetic fields from the proposed 500-kV transmission line would be less than those from the existing 500-kV line in the same corridor. Thus, near the proposed line, magnetic fields would be well above average residential levels. However, the fields from the line would decrease rapidly and approach common ambient levels at distances greater than a few hundred feet from the line. Furthermore, the fields at the edge of the right-of-way would not be above those encountered during normal activities near common sources such as hand-held appliances.

5.0 Electric and Magnetic Field (EMF) Effects

Possible effects associated with the interaction of EMF from transmission lines with people on and near a right-of-way fall into two categories: short-term effects that can be perceived and may represent a nuisance, and possible long-term health effects. Only short-term effects are discussed here. The issue of whether there are long-term health effects associated with transmission-line fields is controversial. In recent years, considerable research on possible biological effects of EMF has been conducted. A review of these studies and their implications for health-related effects is provided in a separate technical report for the environmental impact statement for the proposed Schultz - Hanford Area Transmission Project.

5.1 Electric Fields: Short-term Effects

Short-term effects from transmission-line electric fields are associated with perception of induced currents and voltages or perception of the field. Induced current or spark discharge shocks can be experienced under certain conditions when a person contacts objects in an electric field. Such effects occur in the fields associated with transmission lines that have voltages of 230-kV or higher. These effects could occur under the proposed Schultz - Hanford/Wautoma 500-kV line.

Steady-state currents are those that flow continuously after a person contacts an object and provides a path to ground for the induced current. The amplitude of the steady-state current depends on the induced current to the object in question and on the grounding path. The magnitude of the induced current to vehicles and objects under the proposed line will depend on the electric-field strength and the size and shape of the object. When an object is electrically grounded, the voltage on the object is reduced to zero, and it is not a source of current or voltage shocks. If the object is poorly grounded or not grounded at all, then it acquires some voltage relative to earth and is a possible source of current or voltage shocks.

The responses of persons to steady-state current shocks have been extensively studied, and levels of response documented (Keesey and Letcher, 1969; IEEE, 1978). Primary shocks are those that can result in direct physiological harm. Such shocks will not be possible from induced currents under the existing or proposed lines, because clearances above ground required by the NESC preclude such shocks from large vehicles and grounding practices eliminate large stationary objects as sources of such shocks.

Secondary shocks are defined as those that could cause an involuntary and potentially harmful movement, but no direct physiological harm. Secondary shocks could occur under the proposed 500-kV line when making contact with ungrounded conducting objects such as vehicles or equipment. However, such occurrences are anticipated to be very infrequent. Shocks, when they occur under the 500-kV line, are most likely to be at a nuisance level. Induced currents are extremely unlikely to be perceived off the right-of-way of the proposed line.

Induced currents are always present in electric fields under transmission lines and will be present near the proposed line. However, during initial construction, BPA routinely grounds metal objects that are located on or near the right-of-way. The grounding eliminates these objects as sources of induced current and voltage shocks. Multiple grounding points are used to provide redundant paths for induced current flow. After construction, BPA would respond to any complaints and install or repair grounding to mitigate nuisance shocks.

Unlike fences or buildings, mobile objects such as vehicles and farm machinery cannot be grounded permanently. Limiting the possibility of induced currents from such objects to persons is accomplished in several ways. First, required clearances for above-ground conductors tend to limit field strengths to levels that do not represent a hazard or nuisance. The NESC (IEEE, 1990) requires that, for lines with voltage exceeding 98 kV line-to-ground (170 kV line-to-line), sufficient conductor clearance be maintained to limit the induced short-circuit current in the largest anticipated vehicle under the line to 5 milliamperes (mA) or less. This can be accomplished by limiting access or by increasing conductor clearances in areas where large vehicles could be present. BPA and other utilities design and operate lines to be in compliance with the NESC.

For the proposed line, conductor clearances (50°C conductor temperature) would be increased to at least 54 ft. (16.5 m) over road crossings along the route, resulting in a maximum field of 3.9 kV/m or less at the 3.28 ft. (1 m) height. The largest truck allowed on roads in Washington without a special permit is 14 feet high by 8.5 feet wide by 75 feet long (4.3 x 2.6 x 22.9 m). The induced currents to such a vehicle oriented perpendicular to the line in a maximum field of 3.9 kV/m (at 3.28-foot height) would be 3.5 mA (Reilly, 1979). For smaller trucks, the maximum induced currents for perpendicular orientation to the proposed line would be less than this value. (Larger special-permitted trucks, such as triple trailers, can be up to 105 feet in length. However, because they average the field over such a long distance, the maximum induced current to a 105-foot vehicle oriented perpendicular to the 500-kV line at a road crossing would be 3.3 mA.) Thus, the NESC 5-mA criterion would be met for perpendicular road crossings of the proposed line. These large vehicles are not anticipated to be off highways or oriented parallel to the proposed line. As discussed below, these are worst-case estimates of induced currents at road crossings; conditions for their occurrence are rare. The conductor clearance at each road crossing would be checked during the design stage of the line to ensure that the NESC 5-mA criterion is met. Furthermore, it is BPA policy to limit the maximum induced current from vehicles to 2 mA in commercial parking lots. Line clearances would also be increased in accordance with the NESC, such as over railroads and water areas suitable for sailboating.

Several factors tend to reduce the levels of induced current shocks from vehicles:

(1) Activities are distributed over the whole right-of-way, and only a small percentage of time is spent in areas where the field is at or close to the maximum value.

(2) At road crossings, vehicles are aligned perpendicular to the conductors, resulting in a substantial reduction in induced current.

(3) The conductor clearance at road crossings may not be at minimum values because of lower conductor temperatures and/or location of the road crossing away from midspan.

(4) The largest vehicles are permitted only on certain highways.

(5) Off-road vehicles are in contact with soil or vegetation, which reduces shock currents substantially.

Induced voltages occur on objects, such as vehicles, in an electric field where there is an inadequate electrical ground. If the voltage is sufficiently high, then a spark discharge shock can occur as contact is made with the object. Such shocks are similar to "carpet" shocks that occur, for example, when a person touches a doorknob after walking across a carpet on a dry day. The number and severity of spark discharge shocks depend on electric-field strength. Based on the low frequency of complaints reported by Glasgow and Carstensen (1981) for 500-kV ac transmission lines (one complaint per year for each 1,500 mi. or 2400 km of 500-kV line), nuisance shocks, which are primarily spark discharges, do not appear to be a serious impediment to normal activities under 500-kV lines.

In high electric fields, it is theoretically possible for a spark discharge from the induced voltage on a large vehicle to ignite gasoline vapor during refueling. The probability for exactly the right conditions to occur for ignition is extremely remote. The additional clearance of conductors provided at road crossings reduces the electric field in areas where vehicles are prevalent and reduces the chances for such events. Vehicles should not be refueled under the proposed line unless specific precautions are taken to ground the vehicle and the fueling source.

Under certain conditions, the electric field can be perceived through hair movement on an upraised hand or arm of a person standing on the ground under high-voltage transmission lines. The median field for perception in this manner was 7 kV/m for 136 persons; only about 12 percent could perceive fields of 2 kV/m or less (Deno and Zaffanella, 1982). In areas under the conductors at midspan, the fields at ground level would exceed the levels where field perception normally occurs. In these instances, field perception could occur on the right-of-way of the proposed line. It is unlikely that the field would be perceived beyond the edge of the right-of-way. Where vegetation provides shielding, the field would not be perceived.

Conductive shielding reduces both the electric field and induced effects such as shocks. Persons inside a vehicle cab or canopy are shielded from the electric field. Similarly, a row of trees or a lower-voltage distribution line reduces the field on the ground in the vicinity. Metal pipes, wiring, and other conductors in a residence or building shield the interior from the transmission-line electric field.

Thus, potential impacts of electric fields can be mitigated through grounding policies, adherence to the NESC, and increased clearances above the minimums specified by the NESC. Worst-case levels are used for safety analyses but, in practice, induced currents and voltages are reduced considerably by unintentional grounding. Shielding by conducting objects, such as vehicles and vegetation, also reduces the potential for electric-field effects.

5.2 Magnetic Field: Short-term Effects

Magnetic fields associated with transmission and distribution systems can induce voltage and current in long conducting objects that are parallel to the transmission line. As with electric-field induction, these induced voltages and currents are a potential source of shocks. A fence, irrigation pipe, pipeline, electrical distribution line, or telephone line forms a conducting loop when it is grounded at both ends. The earth forms the other portion of the loop. The magnetic field from a transmission line can induce a current to flow in such a loop if it is oriented parallel to the line. If only one end of the fence is grounded, then an induced voltage appears across the open end of the loop. The possibility for a shock exists if a person closes the loop at the open end by contacting both the ground and the conductor. The magnitude of this potential shock depends on the following factors: the magnitude of the field; the length of the object (the longer the object, the larger the induced voltage); the orientation of the object with respect to the transmission line (parallel as opposed to perpendicular, where no induction would occur); and the amount of electrical resistance in the loop (high resistance limits the current flow).

Magnetically induced currents from power lines have been investigated for many years; calculation methods and mitigating measures are available. A comprehensive study of gas pipelines near transmission lines developed prediction methods and mitigation techniques specifically for induced voltages on pipelines (Dabkowski and Taflove, 1979; Taflove and Dabkowski, 1979). Similar techniques and procedures are available for irrigation pipes and fences. Grounding policies employed by utilities for long fences reduce the potential magnitude of induced voltage.

The magnitude of the coupling with both pipes and fences is very dependent on the electrical unbalance (unequal currents) among the three phases of the line. Thus, a distribution line where a phase outage may go unnoticed for long periods of time can represent a larger source of induced currents than a transmission line where the loads are well-balanced (Jaffa and Stewart, 1981).

Knowledge of the phenomenon, grounding practices, and the availability of mitigation measures mean that magnetic-induction effects from the proposed 500-kV transmission line will be minimal.

Magnetic fields from transmission and distribution facilities can interfere with certain electronic equipment. Magnetic fields can cause distortion of the image on VDTs and computer monitors. The threshold field for interference depends on the type and size of monitor and the frequency of the field. Interference has been observed for certain monitors at fields at or below 10 mG (Baishiki et al., 1990; Banfai et al., 2000). Generally, the problem arises when computer monitors are in use near electrical distribution facilities in large office buildings. Fields from the proposed line would fall below this level at approximately 185 ft. (56.4 m) from the centerline.

Interference from magnetic fields can be eliminated by shielding the affected monitor or moving it to an area with lower fields. Similar mitigation methods could be applied to other sensitive electronics, if necessary. Interference from 60-Hz fields with computers and control circuits in vehicles and other equipment is not anticipated at the field levels found under and near the proposed 500-kV transmission line.

6.0 Regulations

Regulations that apply to transmission-line electric and magnetic fields fall into two categories. Safety standards or codes are intended to limit or eliminate electric shocks that could seriously injure or kill persons. Field limits or guidelines are intended to limit electric- and magnetic-field exposures that can cause nuisance shocks or might cause health effects. In no case has a limit or standard been established because of a known or demonstrated health effect.

The proposed line would be designed to meet the NESC (IEEE, 1990), which specifies how far transmission-line conductors must be from the ground and other objects. The clearances specified in the code provide safe distances that prevent harmful shocks to workers and the public. In addition, people who live and work near transmission lines must be aware of safety precautions to avoid electrical (which is not necessarily physical) contact with the conductors. For example, farmers should not up-end irrigation pipes under a transmission or other electrical line. In addition, as a matter of safety, the NESC specifies that electric-field-induced currents from transmission lines must be below the 5 mA ("let go") threshold deemed a lower limit for primary shock. BPA publishes and distributes a brochure that describes safe practices to protect against shock hazards around power lines (USDOE, 1995).

Field limits or guidelines have been adopted in several states and countries and by national and international organizations. Electric-field limits have generally been based on minimizing nuisance shocks or field perception. The intent of magnetic-field limits has been to limit exposures to existing levels, given the uncertainty of their potential for health effects.

There are currently no national standards in the United States for 60-Hz electric and magnetic fields. Several states have been active in establishing mandatory or suggested limits on 60-Hz electric and (in two cases) magnetic fields. Six states have specific electric-field limits that apply to transmission lines: Florida, Minnesota, Montana, New Jersey, New York, and Oregon. These regulations are summarized in Table 5, adapted from TDHS Report (1989). Florida and New York have established regulations for magnetic fields. The state of Washington does not have limits for either electric or magnetic fields from transmission lines.

Electric-field limits for the states have been given in terms of maximum field or edge-of-right-of-way field, or both. Except for Florida, regulations have not explicitly stated the operating conditions under which the limits apply. The Florida regulation, adopted after extensive public hearings and controversy, states: "Although there is no conclusive evidence that there is any danger or hazard to public health at levels of existing 60-hertz electric and magnetic fields found in Florida, there is evidence of a potential for adverse health effects on the public. Further research is needed to determine if there are effects and the exposure levels at which effects may occur" (Florida Department of Environmental Regulation, 1989: Chapter 17-274:2). The Florida <u>electric-field</u> strength standard is based on 1) the avoidance of perception of the field at the edge or on the right-of-way, and 2) the levels near existing facilities. The electric-field strength limit in Florida has been set at 2 kV/m at the edge of the right-of-way and 8 kV/m on the right-of-way for 230-kV or smaller lines. For 500-kV lines, the electric field shall not exceed 10 kV/m on the right-of-way and 2 kV/m at the edge.

The Florida <u>magnetic-field</u> limit at the edge of the right-of-way is 150 mG for lines of 230 kV or less, and 200 mG for 500-kV lines. There is no stated limit on the right-of-way.

The Minnesota 8-kV/m maximum field limit is applied on a case-by-case basis by the Minnesota Environmental Quality Board (MEQB), which has jurisdiction over lines of nominal voltage 200 kV and higher. The limit is included in Construction Permits granted by the MEQB rather than in a formal rule (e.g., MEQB, 1977). Minnesota does not have an edge-of-right-of-way field limit.

The Montana Board of Natural Resources and Conservation (BNRC) imposed a 1 kV/m electric-field limit at the edge of the right-of-way in residential and subdivided areas for the BPA Garrison-Spokane 500-kV Transmission Project (BNRC, 1983). The administrative rules incorporating this requirement were adopted in 1984 (Jamison, 1986). These rules apply to lines designed for operation at 69 kV and higher, as the BNRC has routing authority over them. (An affected landowner may waive the 1 kV/m requirement.) At road crossings, a 7-kV/m limit must be observed. The 1-kV/m electric-field limit was adopted because of the degree of protection and assurance to the public it provided and because of the small amount of additional right-of-way required (Jamison, 1986). Although Montana does not have a magnetic-field limit, the imposition of the 1-kV/m electric-field limit ensures that edge-of-right-of-way magnetic fields will be less than 50 mG (Jamison, 1986).

In New Jersey, the Department of Environmental Protection (NJDEP), Bureau of Radiation Protection, established interim guidelines for maximum field levels at the edge of the right-of-way (NJDEP, 1981). Their 3-kV/m limit is in the form of a resolution and is not enforced, but serves rather as a guideline for evaluating complaints.

The New York edge-of-right-of-way electric-field limit resulted from the extensive public hearings on 765-kV lines before the New York Public Service Commission (NYPSC) from 1975 to 1977. The opinions issued by the NYPSC in this case required that the interim edge-of-right-of-way electric-field limit be equivalent to that for 345-kV lines (NYPSC, 1978b; 1978a). This resulted in an edge-of-right-of-way limit of approximately 1.6 kV/m. This limit was explicitly implemented by specification of a 350-ft. (107-m) right-of-way width for 765-kV lines. In addition, electric fields on public roads, private roads, and other terrain were limited to 7, 11, and 11.8 kV/m, respectively. These values were intended to limit the induced current to 4.5 mA for the largest anticipated vehicle. The NYPSC also required that the utilities involved fund additional research in the area of biological effects of EMF. The final report of the New York State Scientific Advisory Program was issued in 1987 (Ahlbom et al., 1987). New York adopted an edge-of-right-of-way magnetic-field standard of 200 mG in August 1990 (TDHS Report, 1990).

Oregon's formal rule in its transmission line siting procedures specifically addresses field limits. The Oregon limit of 9 kV/m for electric fields is applied to areas accessible to the public (Oregon, 1980). The Oregon rule also addresses grounding practices, audible noise, and radio interference.

Government agencies and utilities operating transmission systems have established design criteria that include EMF levels. BPA has maximum allowable electric fields of 9 and 5 kV/m on and at the edge of the right-of-way, respectively (USDOE, 1996). BPA also has maximum-allowable electric-field strengths of 5 kV/m, 3.5 kV/m, and 2.5 kV/m for road crossings, shopping center parking lots, and commercial/ industrial parking lots, respectively. These levels are based on limiting the maximum short-circuit currents from anticipated vehicles to less than 1 mA in shopping center lots and to less than 2 mA in commercial parking lots.

Electric-field limits for overhead power lines have also been established in other countries (Maddock, 1992). Limits for magnetic fields from overhead power lines have not been explicitly established anywhere except in Florida and New York. However, general guidelines and limits on EMF have been established for occupational and public exposure in several countries and by national and international organizations.

The American Conference of Governmental Industrial Hygienists (ACGIH) sets guidelines (Threshold Limit Values or TLV) for occupational exposures to environmental agents (ACGIH, 2000). In general, a TLV represents the level below which it is believed that nearly all workers may be exposed repeatedly without adverse health effects. For EMF, the TLVs represent ceiling levels. For 60-Hz electric fields, occupational exposures should not exceed the TLV of 25 kV/m. However, the ACGIH also recognizes the potential for startle reactions from spark discharges and short-circuit currents in fields greater than 5-7 kV/m, and recommends implementing grounding practices. They recommend the use of conductive clothing for work in fields exceeding 15 kV/m. The TLV for occupational exposure to 60-Hz magnetic fields is a ceiling level of 10 G (10,000 mG) (ACGIH, 2000).

Electric and magnetic fields from various sources (including automobile ignitions, appliances and, possibly, transmission lines) can interfere with implanted cardiac pacemakers. In light of this potential problem, manufacturers design devices to be immune from such interference. However, research has shown that these efforts have not been completely successful and that a few models of pacemakers could be affected by 60-Hz fields from transmission lines. There were also numerous models of pacemakers that were not affected by fields even larger than those found under transmission lines. Because of the known potential for interference with pacemakers by 60-Hz fields, field limits for pacemaker wearers have been established by the ACGIH. They recommend that wearers of pacemakers and similar medical-assist devices limit their exposure to electric fields of 1 kV/m or less and to magnetic fields to 1 G (1,000 mG) or less (ACGIH, 2000).

The International Committee on Non-ionizing Radiation Protection (ICNIRP), working in cooperation with the World Health Organization (WHO) has developed guidelines for occupational and public exposures to EMF (ICNIRP, 1998). For occupational exposures at 60 Hz, the recommended limits to exposure are 8.3 kV/m for electric fields and 4.2 G (4,200 mG) for magnetic fields. The electric-field level can be exceeded, provided precautions are taken to prevent spark discharge and induced current shocks. For the general public, the ICNIRP guidelines recommend exposure limits of 4.2 kV/m for electric fields and 0.83 G (830 mG) for magnetic fields (ICNIRP, 1998).

ICNIRP has also established guidelines for contact currents, which could occur when a grounded person contacts an ungrounded object in an electric field. The guideline levels are 1.0 mA for occupational exposure and 0.5 mA for public exposure.

The electric fields from the proposed 500-kV line would meet the ACGIH standards, provided wearers of pacemakers and similar medical-assist devices are discouraged from unshielded right-of-way use. (A passenger in an automobile under the line would be shielded from the electric field.) The electric fields in limited areas on the right-of-way would exceed the ICNIRP guideline for public exposure. The magnetic fields from the proposed line would be below the ACGIH and IRPA/INIRC limits. The electric fields present on the right-of-way could induce currents in ungrounded vehicles that exceeded the ICNIRP level of 0.5 mA.

The estimated peak electric fields on the right-of-way of the proposed transmission line would meet limits set in Florida, New York and Oregon, but not those of Minnesota and Montana (see Table 5). The BPA maximum allowable electric field limit would be met for all configurations of the proposed line. The edge of right-of-way electric fields from the proposed line would be below limits set in Florida and New Jersey, but above those in Montana and New York.

The magnetic field at the edge of the right-of-way from the proposed line would be below the regulatory levels of states where such regulations exist.

7.0 Audible Noise

7.1 Basic Concepts

Audible noise (AN), as defined here, represents an unwanted sound, as from a transmission line, transformer, airport, or vehicle traffic. Sound is a pressure wave caused by a sound source vibrating or displacing air. The ear converts the pressure fluctuations into auditory sensations. AN from a source is superimposed on the background or ambient noise that is present before the source is introduced.

The amplitude of a sound wave is the incremental pressure resulting from sound above atmospheric pressure. The sound-pressure level is the fundamental measure of AN; it is generally measured on a logarithmic scale with respect to a reference pressure. The sound-pressure level (SPL) in decibels (dB) is given by:

$$SPL = 20 \log (P/P_o) dB$$

where P is the effective rms (root-mean-square) sound pressure, P_o is the reference pressure, and the logarithm (log) is to the base 10. The reference pressure for measurements concerned with hearing is usually taken as 20 micropascals (Pa), which is the approximate threshold of hearing for the human ear. A logarithmic scale is used to encompass the wide range of sound levels present in the environment. The range of human hearing is from 0 dB up to about 140 dB, a ratio of 10 million in pressure (EPA, 1978).

Logarithmic scales, such as the decibel scale, are not directly additive: to combine decibel levels, the dB values must be converted back to their respective equivalent pressure values, the total rms pressure level found, and the dB value of the total recalculated. For example, adding two sounds of equal level on the dB scale results in a 3 dB increase in sound level. Such an increase in sound pressure level of 3 dB, which corresponds to a doubling of the energy in the sound wave, is barely discernible by the human ear. It requires an increase of about 10 dB in SPL to produce a subjective doubling of sound level for humans. The upper range of hearing for humans (140 dB) corresponds to a sharply painful response (EPA, 1978).

Humans respond to sounds in the frequency range of 16 to 20,000 Hz. The human response depends on frequency, with the most sensitive range roughly between 2000 and 4000 Hz. The frequency-dependent sensitivity is reflected in various weighting scales for measuring audible noise. The A-weighted scale weights the various frequency components of a noise in approximately the same way that the human ear responds. This scale is generally used to measure and describe levels of environmental sounds such as those from vehicles or occupational sources. The A-weighted scale is also used to characterize transmission-line noise. Sound levels measured on the A-scale are expressed in units of dB(A) or dBA.

AN levels and, in particular, corona-generated audible noise (see below) vary in time. In order to account for fluctuating sound levels, statistical descriptors have been developed for environmental noise. Exceedence levels (L levels) refer to the A-weighted sound level that is exceeded for a specified percentage of the time. Thus, the L_5 level refers to the noise level that is exceeded only 5 percent of the time. L_{50} refers to the sound level exceeded 50 percent of the time. Sound-level measurements and predictions for transmission lines are often expressed in terms of exceedence levels, with the L_5 level representing the maximum level and the L_{50} level representing a median level.

Table 6 shows AN levels from various common sources. Clearly, there is wide variation. Noise exposure depends on how much time an individual spends in different locations. Outdoor noise generally does not contribute to indoor levels (EPA, 1974). Activities in a building or residence generally dominate interior AN levels. The amount of sound attenuation (reduction) provided by buildings is given in Table 7. Assuming that residences along the line route fall in the "warm climate, windows open" category, the typical sound attenuation provided by a house is about 12 dBA.

The BPA design criterion for corona-generated audible noise (L_{50}, foul weather) is 50 ±2 dBA at the edge of the right-of-way (Perry, 1982). The Washington Administrative Code provides noise limitations by class of property, residential, commercial or industrial (Washington State, 1975). Transmission lines are classified as industrial and may cause a maximum permissible noise level of 60 dBA to intrude into residential property. During nighttime hours (10:00 pm to 7:00 am), the maximum permissible limit for noise from industrial to residential areas is reduced to 50 dBA. This latter level applies to transmission lines that operate continuously. The state of Washington Department of Ecology accepts the 50 dBA level at the edge of the right-of-way for transmission lines, but encouraged BPA to design lines with lower audible noise levels (WDOE, 1981).

The EPA has established a guideline of 55 dBA for the annual average day-night level (L_{dn}) in outdoor areas (EPA, 1978). In computing this value, a 10 dB correction (penalty) is added to night-time noise between the hours of 10 pm and 7 am.

7.2 Transmission-line Audible Noise

Corona is the partial electrical breakdown of the insulating properties of air around the conductors of a transmission line. In a small volume near the surface of the conductors, energy and heat are dissipated. Part of this energy is in the form of small local pressure changes that result in audible noise. Corona-generated audible noise can be characterized as a hissing, crackling sound that, under certain conditions, is accompanied by a 120-Hz hum.

Corona-generated audible noise is of concern primarily for contemporary lines operating at voltages of 345 kV and higher during foul weather. The conductors of high-voltage transmission lines are designed to be corona-free under ideal conditions. However, protrusions on the conductor surface—particularly water droplets on or dripping off the conductors—cause electric fields near the conductor surface to exceed corona onset levels, and corona occurs. Therefore, audible noise from transmission lines is generally a foul-weather (wet-conductor) phenomenon. Wet conductors can occur during periods of rain, fog, snow, or icing. Based on meteorologic records near the route of the proposed transmission line, such conditions are expected to occur less than 7 percent of the time during the year. For a few months after line construction, residual grease or oil on the conductors can cause water to bead up on the surface. This results in more corona sources and slightly higher levels of audible noise and electromagnetic interference if the line is energized. However, the new conductors "age" in a few months, and the level of corona activity decreases to the predicted equilibrium value. During fair weather, insects and dust on the conductor can also serve as sources of corona. The proposed line has been designed with three subconductors per phase to yield acceptable corona levels.

7.3 Predicted Audible Noise Levels

The predicted levels of corona-generated audible noise for the proposed line operated at a voltage of 540 kV are given in Table 8 and plotted in Figure 4 for selected configurations. For comparison, Table 8 also gives the calculated levels for the existing parallel lines. Audible noise levels are calculated for average voltage and average conductor heights for fair- and foul-weather conditions. The calculated median level (L_{50}) during foul weather at the edge of the proposed Schultz - Wautoma right-of-way is about 50 dBA, which is comparable with levels at the edges of existing 500-kV lines in Washington and lower than the levels from the existing 500-kV lines in the corridor just east of Schultz substation.

For configurations with parallel 230-kV lines (Configurations D-1 to D-4), the AN level at the edge of the right-of-way adjacent to the proposed line would be 50 dBA. For the Configuration A-4, which entails replacement of an existing 500-kV line with the proposed line, the AN level at the edge of the right-of-way would decrease by about 8 dBA. The AN at the edge of the right-of-way of the realigned Sickler-Schultz 500-kV line would be 59 dBA. The proposed Schultz-Wautoma line would increase the level at the edge of the existing 230-kV lines by 8-to-12 dBA. This increase would be perceived as a doubling of the noise level.

During fair-weather conditions, which occur about 92 percent of the time, audible noise levels would be about 20 dBA lower (if corona were present). These lower levels could be masked by ambient noise on and off the right-of-way.

7.4 Discussion

The calculated foul-weather corona noise levels for the proposed line would be comparable to or less than those from existing 500-kV lines in Washington. During fair weather, noise from the conductors might be perceivable on the right-of-way, but beyond the right-of-way it will likely be masked or so low as not to be perceived.

Off the right-of-way, the levels of audible noise from the proposed line would be well below the 55 dBA level that can produce interference with speech outdoors. Since residential buildings provide significant sound attenuation (-12 dBA with windows open; -24 dBA with windows closed), the noise levels off the right-of-way would be well below the 45 dBA level required for interference with speech indoors. It is also highly unlikely that indoor noise levels from the line would exceed the 35 dBA level where sleep interference can occur (EPA, 1973; EPA, 1978). Since corona is a foul-weather phenomenon, people tend to be inside with windows possibly closed, providing additional attenuation when corona noise is present. In addition, ambient noise levels can be high during such periods (due to rain hitting foliage or buildings), and can mask corona noise.

The 50-dBA level at the edge of the right-of-way for the proposed line would meet Washington Administrative Code limits for transmission lines. Noise levels near the existing Vantage-Schultz and Sickler-Schultz 500-kV lines exceed the limit and presumably are allowed because of the ages of the lines.

The computed annual L_{dn} level for transmission lines operating in areas with about 7 percent foul weather is about $L_{dn} = L_{50} - 4$ dB (Bracken, 1987). Therefore, assuming such conditions in the Schultz - Hanford area, the estimated L_{dn} at the edge of the right-of-way would be approximately 46 dBA, which is below the EPA L_{dn} guideline of 55 dBA.

7.5 Conclusion

Along the proposed line route, there would be an increase in the perceived noise above ambient levels during foul weather at the edges of new right-of-way. Along those sections of the proposed route where new right-of-way parallels existing 230-kV right-of-way, increases in line noise levels during foul weather at the edge of the right-of-way adjacent to the existing lines would be perceived as a doubling of the noise level. Along new and existing corridors, the corona-generated noise during foul weather might be masked to some extent by naturally occurring sounds such as wind and rain on foliage. During fair weather, the noise off the right-of-way would probably not be detectable above ambient levels. The noise levels from the proposed line would be below levels identified as causing interference with speech or sleep. The audible noise from the transmission line would be below EPA guideline levels and would meet the BPA design criterion that complies with the Washington state noise regulations.

8.0 Electromagnetic Interference

8.1 Basic Concepts

Corona on transmission-line conductors can also generate electromagnetic noise in the frequency bands used for radio and television signals. The noise can cause radio and television interference (RI and TVI). In certain circumstances, corona-generated electromagnetic interference (EMI) can also affect communications systems and other sensitive receivers. Interference with electromagnetic signals by corona-generated noise is generally associated with lines operating at voltages of 345 kV or higher. This is especially true of interference with television signals. The three-conductor bundle design of the proposed 500-kV line is intended to mitigate corona generation and thus keep radio and television interference levels at acceptable levels.

Spark gaps on distribution lines and on low-voltage wood-pole transmission lines are a more common source of RI/TVI than is corona from high-voltage electrical systems. This gap-type interference is primarily a fair-weather phenomenon caused by loose hardware and wires. The proposed transmission line would be constructed with modern hardware that eliminates such problems and therefore minimizes gap noise. Consequently, this source of EMI is not anticipated for the proposed line.

No state has limits for either RI or TVI. In the United States, electromagnetic interference from power transmission systems is governed by the Federal Communications Commission (FCC) Rules and Regulations presently in existence (FCC, 1988). A power transmission system falls into the FCC category of "incidental radiation device," which is defined as "a device that radiates radio frequency energy during the course of its operation although the device is not intentionally designed to generate radio frequency energy." Such a device "shall be operated so that the radio frequency energy that is emitted does not cause harmful interference. In the event that harmful interference is caused, the operator of the device shall promptly take steps to eliminate the harmful interference." For purposes of these regulations, harmful interference is defined as: "any emission, radiation or induction which endangers the functioning of a radio navigation service or of other safety services or seriously degrades, obstructs or repeatedly interrupts a radio communication service operating in accordance with this chapter" (FCC, 1988: Vol II, part 15. 47CFR, Ch. 1).

Electric power companies have been able to work quite well under the present FCC rule because harmful interference can generally be eliminated. It has been estimated that more than 95 percent of power-line sources that cause interference are due to gap-type discharges. These can be found and completely eliminated, when required to prevent interference (USDOE, 1980). Complaints related to corona-generated interference occur infrequently. This is especially true with the advent of cable television and satellite television, which are not subject to corona-generated interference. Mitigation of corona-generated interference with conventional radio and television receivers can be accomplished in several ways, such as use of a directional antenna or relocation of an existing antenna (USDOE, 1977; USDOE, 1980; Loftness et al., 1981).

8.2 Radio Interference (RI)

Radio reception in the AM broadcast band (535 to 1605 kilohertz (kHz)) is most often affected by corona-generated EMI. FM radio reception is rarely affected. Generally, only residences very near to transmission lines can be affected by RI. The IEEE Radio Noise Design Guide identifies an acceptable limit of fair-weather RI as expressed in decibels above 1 microvolt per meter (dBµV/m) of about 40 dBμV/m at 100 ft. (30 m) from the outside conductor (IEEE Committee Report, 1971). As a general rule, average levels during foul weather (when the conductors are wet) are 16 to 22 dBμV/m higher than average fair-weather levels.

8.3 Predicted RI Levels

Table 9 gives the predicted fair- and foul-weather RI levels at 100 ft. (30 m) from the outside conductor for the proposed 500-kV line in the eight configurations. Median foul-weather levels would be about 17 dB higher than the fair-weather levels. The predicted L_{50} fair-weather level at the edge of the new right-of-way is 46 dBμV/m for 540-kV line operation; at 100 ft. (30 m) from the outside conductor, the level is 40 dBμV/m or less. Predicted fair-weather L_{50} levels are comparable with those for other existing 500-kV lines and lower than that from the existing 500-kV Sickler-Schultz line (47 dBμV/m at 100 ft. [30 m]). Predictions indicate that fair-weather RI will meet the IEEE 40 dBμV/m criterion at distances greater than about 100 ft. (30 m) from the outside conductor of the proposed line in all configurations.

8.4 Television Interference (TVI)

Corona-caused TVI occurs during foul weather and is generally of concern for transmission lines with voltages of 345 kV or above, and only for conventional receivers within about 600 ft. (183 m) of a line. As is the case for RI, gap sources on distribution and low-voltage transmission lines are the principal observed sources of TVI. The use of modern hardware and construction practices for the proposed line would minimize such sources.

8.5 Predicted TVI Levels

Table 10 shows TVI levels predicted at 100 ft. (30 m) from the outside conductor of the proposed line operating at 540 kV and from existing lines. At this distance, the foul-weather TVI level predicted for the proposed line is 26 dBμV/m or less. This is comparable with TVI levels from other existing BPA 500-kV lines, and lower than that from the existing Sickler-Schultz 500-kV line (33 dBμV/m at 100 ft. [30 m]).

There is a potential for interference with television signals at locations very near the proposed line in fringe reception areas. However, several factors reduce the likelihood of occurrence. Corona-generated TVI occurs only in foul weather; consequently, signals will not be interfered with most of the time, which is characterized by fair weather. Because television antennas are directional, the impact of TVI is related to the location and orientation of the antenna relative to the transmission line. If the antenna were pointed away from the line, then TVI from the line would affect reception much less than if the antenna were pointed towards the line. Since the level of TVI falls off with distance, the potential for interference becomes minimal at distances greater than several hundred feet from the centerline.

Other forms of TVI from transmission lines are signal reflection (ghosting) and signal blocking caused by the relative locations of the transmission structure and the receiving antenna with respect to the incoming television signal. Television systems that operate at higher frequencies, such as satellite receivers, are not affected by corona-generated TVI. Cable television systems are similarly unaffected.

Interference with television reception can be corrected by any of several approaches: improving the receiving antenna system; installing a remote antenna; installing an antenna for TV stations less vulnerable to interference; connecting to an existing cable system; or installing a translator (cf. USDOE, 1977). BPA has an active program to identify, investigate, and mitigate legitimate RI and TVI complaints. It is anticipated that any instances of TVI caused by the proposed line could be effectively mitigated.

8.6 Interference with Other Devices

Corona-generated interference can conceivably cause disruption on other communications bands such as the citizen's (CB) and mobile bands. However, mobile-radio communications are not susceptible to transmission-line interference because they are generally frequency modulated (FM). Similarly, cellular telephones operate at a frequency of about 900 MHz, which is above the frequency where corona-generated interference is prevalent. In the unlikely event that interference occurs with these or other communications, mitigation can be achieved with the same techniques used for television and AM radio interference.

8.7 Conclusion

Predicted EMI levels for the proposed 500-kV transmission line are comparable to those from existing 500-kV lines. If interference should occur, there are various methods for correcting it; BPA has a program to respond to legitimate complaints. Therefore, the anticipated impacts of corona-generated interference on radio, television, or other reception would be minimal.

9.0 Other Corona Effects

Corona is visible as a bluish glow or as bluish plumes. The proposed 500-kV line is designed to have lower corona levels than is present on the older 500-kV lines in the area. Therefore corona on the conductors would be less visible on this line than on others and would be observable only under the darkest conditions and probably only with the aid of binoculars. Without a period of adaptation for the eyes and without intentional looking for the corona, it probably would not be noticeable.

When corona is present, the air surrounding the conductors is ionized and many chemical reactions take place, producing small amounts of ozone and other oxidants. Ozone is approximately 90 percent of the oxidants, while the remaining 10 percent is composed principally of nitrogen oxides. The national primary ambient air quality standard for photochemical oxidants, of which ozone is the principal component, is 235 micrograms/cubic meter) or 120 parts per billion. The maximum incremental ozone levels at ground level produced by corona activity on the proposed transmission line during foul weather would be much less than 1 part per billion. This level is insignificant when compared with natural levels and fluctuations in natural levels.

10.0 Summary

Electric and magnetic fields from the proposed transmission line have been characterized using well-known techniques accepted within the scientific and engineering community. The expected electric-field levels from the proposed line at minimum design clearance would be comparable to those of other 500-kV lines in Washington and elsewhere. The expected magnetic-field levels from the proposed line would be comparable to or less than those from other 500-kV lines in Washington and elsewhere.

The peak electric field expected under the proposed line would be 8.9 kV/m; the maximum value at the edge of the right-of-way would be about 2.0 kV/m. Clearances at road crossings would be increased to reduce the peak electric-field value to 3.9 kV/m.

Under maximum current conditions, magnetic-field levels would be as follows:

- the maximum magnetic fields under the proposed line would be 244 mG;

- at the edge of the right-of-way nearest to the proposed 500-kV line, the magnetic field would be 55 to 66 mG, depending on the configuration.

The electric fields from the proposed line would meet regulatory limits for public exposure in some states, but could exceed the regulatory limits or guidelines for peak fields established in other states and by ICNIRP. The magnetic fields from the proposed line would be within the regulatory limits of the two states that have established them and within guidelines for public exposure established by ICNIRP. Washington does not have any electric- or magnetic-field regulatory limits or guidelines.

Short-term effects from transmission-line fields are well understood and can be mitigated. Nuisance shocks arising from electric-field induced currents and voltages could be perceivable on the right-of-way of the proposed line. It is common practice to ground permanent conducting objects during and after construction to mitigate against such occurrences.

Corona-generated audible noise from the line would be perceivable during foul weather. The levels would be comparable to those near existing 500-kV transmission lines in Washington, would be in compliance with noise regulations in Washington, and would be below levels specified in EPA guidelines.

Corona-generated electromagnetic interference from the proposed line would be comparable to or less than that from existing 500-kV lines in Washington. Radio interference levels would be below limits identified as acceptable. Television interference, a foul-weather phenomenon, is anticipated to be comparable to or less than that from existing 500-kV lines in Washington; if legitimate complaints arise, BPA has a mitigation program.

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Table 1: Physical and electrical characteristics of Schultz-Hanford Area Project configurations (4 pages).

	New Configurations			
Segment-Configuration	**A-1**	**A-2**	**A-3**	
Line Description	**Schultz-Hanford 500-kV Only**	**Sickler-Schultz 500-kV Only**	**Sickler-Schultz 500-kV**	**Rocky Reach-Maple Valley 345-kV**
Voltage, kV Maximum/Average[1]	550/540	550/540	550/540	362/358
Peak current, A Existing/Proposed[2]	— /1436	— /-1478	— /-1478	-459/-470
Electric phasing	BAC	BAC	BAC	ABC
Clearance, ft. minimum/Average[1]	33/47	33/47	33/47	31/45
Centerline distance-direction from Schultz – Hanford 500-kV Line, ft.	—	N/A	N/A	150-S[3]
Centerline distance to edge of ROW, ft.	75	75	75	75
Tower configuration	Delta	Delta	Delta	Flat
Phase spacing, ft.	40 H, 28.7 V	40H, 27.5V	40H, 27.5V	36H
Conductor: #/diameter, in.; spacing, in.	3/1.302; 17.04	2/1.602; 18	2/1.602; 18	1/1.602

1 Average voltage and average clearance used for corona calculations.
2 Minus sign indicates current flow in opposite direction to flow in parallel proposed Schultz – Hanford line.
3 Distance from centerline of realigned Sickler-Schultz 500-kV line.

Table 1, continued

	Existing Configurations						
Segment-Configuration	A-4						
Line Description	Grand Coulee-Schultz 500-kV DC (DC)		Columbia-Ellensburg 115-kV	Covington-Columbia #3 & Olympia-Grand Coulee DC		Sickler-Schultz 500-kV[4]	Vantage-Schultz 500-kV[3]
	#2	#1		230-kV	287-kV		
Voltage, kV Maximum/Average[1]	550/540	550/540	121/117	242/235	301/292	550/540	550/540
Peak current, A Existing/Proposed[2]	-1470/-1653	-1470/-1653	-477/-453	-316/-341	-494/-486	-1338/—	1355/738
Electric phasing	BAC	BCA	CBA	BCA	BAC	BAC	ABC
Clearance, ft. minimum/Average[1]	33/47	33/47	25/35	30/42	30/42	33/47	33/47
Centerline distance-direction from Schultz–Hanford 500-kV line, ft.	500-N		375-N	250-N		125-N	0[3]
Centerline distance to edge of ROW, ft.	62.5	—	—	—	—	—	75
Tower configuration	Vertical	Vertical	Flat	Vertical	Vertical	Delta	Flat
Phase spacing, ft.	36.5, 56.5, 36.5H; 36V	36.5, 56.5, 36.5H; 36V	12H	31, 47, 31H; 21V	31, 47, 31H; 21V	40H, 27.5V	49H
Conductor: #/Diameter, in. ; spacing, in.	3/1.602; 17.04	3/1.602; 17.04	1/1.108	1/1.382	1/1.382	2/1.602; 18	1/2.50

1 Average voltage and average clearance used for corona calculations.
2 Minus sign indicates current flow in opposite direction to flow in parallelproposed Schultz – Hanford line.
4 Proposed Schultz-Hanford/Wautoma 500-kV line will replace existing Vantage-Schultz 500-kV and existing Vantage-Schultz 500-kV will replace Sickler-Schultz 500-kV. Sickler-Schultz 500-kV will be realigned north of Schultz substation (Configurations A-2 and A-3).

Table 1, continued

	Existing Configurations				
Segment-Configuration	**D-1**	**D-2**			
Line Description	**Vantage-Midway 230-kV**	**N. Bonneville - Midway 230-kV**	**Midway-Moxee 115-kV**	**Midway-Grandview 115-kV**	**Big Eddy-Midway 230-kV**
Voltage, kV Maximum/Average[1]	242/235	242/235	121/117	121/117	242/235
Peak current, A Existing/Proposed[2]	609/593	537/518	153/154	308/293	779/730
Electric phasing	ABC	ABC	ABC	ABC	ABC
Clearance, ft. minimum/Average[1]	30/42	30/42	25/35	25/35	30/42
Centerline distance-direction from Schultz–Wautoma 500-kV line, ft.	125-E	375-E	287.5-E	237.5-E	137.5-E
Centerline distance to edge of ROW, ft.	50	187.5	—	—	62.5
Tower configuration	Flat	Flat	Flat	Flat	Flat
Phase spacing, ft.	27H	27H	12H	12H	27H
Conductor: #/Diameter, in.; spacing, in.	1/1.0	1/1.108	1/0.655	1/0.563	1/1.382

1 Average voltage and average clearance used for corona calculations.
2 Minus sign indicates current flow in opposite direction to flow in parallel proposed Schultz – Hanford line.

Table 1, continued:

	Existing Configurations			
Segment-Configuration	**D-3**			**D-4**
Line Description	**N. Bonneville - Midway 230-kV**	**Midway-Grandview 115-kV**	**Big Eddy-Midway 230-kV**	**Big Eddy-Midway 230-kV**
Voltage, kV Maximum/Average[1]	242/235	121/117	242/235	242/235
Peak current, A Existing/Proposed[2]	537/518	308/293	779/730	779/730
Electric Phasing	ABC	ABC	ABC	ABC
Clearance, ft. minimum/Average[1]	30/42	25/35	30/42	30/42
Centerline distance-direction from Schultz–Wautoma 500-kV line, ft.	325-E	237.5-E	137.5-E	137.5-E
Centerline distance to edge of ROW, ft.	187.5	—	62.5	62.5
Tower configuration	Flat	Flat	Flat	Flat
Phase spacing, ft.	27H	12H	27H	27H
Conductor: #/diameter, in. ; spacing, in.	1/1.108	1/0.563	1/1.382	1/1.382

1 Average voltage and average clearance used for corona calculations.
2 Minus sign indicates current flow in opposite direction to flow in parallel proposed Schultz – Hanford line.

Table 2: Possible segment configurations for Schultz - Hanford Area Project

Segment-Configuration	Description of other lines in corridor with Schultz–Hanford/Wautoma 500-kV line	Possible segments with same configuration	Miles
A-1	Schultz–Hanford/Wautoma 500-kV line only	A, B, C, E, F	22.4, 10.3, 30.6, 23.8, 31.9
A-2	Realigned Sickler-Schultz 500-kV only. (No Schultz-Hanford/Wautoma 500-kV)	A	1.0
A-3	Realigned Sickler-Schultz 500-kV Rocky Reach-Maple Valley 345-kV (No Schultz-Hanford/Wautoma 500-kV)	A	1.15
A-4	Grand Coulee-Schultz #2 and #1 DC 500-kV Columbia-Ellensburg 115-kV Covington-Columbia #3 230-kV/ Olympia-Grand Coulee 287-kV DC Vantage-Schultz 500-kV	A	1.88
D-1	Vantage-Midway 230-kV	D	19.4
D-2	N. Bonneville-Midway 230-kV Midway-Moxee 115-kV Midway-Grandview 115-kV Big Eddy-Midway 230-kV	D	4.51
D-3	N. Bonneville-Midway 230-kV Midway-Grandview 115-kV Big Eddy-Midway 230-kV	D	1.19
D-4	Big Eddy-Midway 230-kV	D	2.2

Table 3: Calculated electric fields for configurations of the proposed Schultz–Hanford/Wautoma 500-kV line operated at maximum voltage. Configurations are described in Tables 1 and 2. (6 pages)

a) Configuration A-1: Schultz – Hanford 500-kV line only

Configuration	Proposed A-1		Existing	
ROW width, ft.	150		—	
Line	Schultz–Hanford/Wautoma 500-kV		—	
Clearance	min.	avg.	—	—
Peak field, kV/m	8.9	4.9	—	—
Edge of ROW, kV/m	2.0	2.0	—	—

b) Configuration A-2: Realigned Sickler-Schultz - 500-kV line only

Configuration	Proposed A-2		Existing	
ROW width, ft. (m)	150 (46)		—	
Line	Sickler-Schultz 500-kV		—	
Clearance	min.	avg.	—	—
Peak field, kV/m	8.4	4.6	—	—
Edge of ROW, kV/m	1.8	1.8	—	—

c) Configuration A-3: Realigned Sickler-Schultz 500-kV and Rocky Reach-Maple Valley 345-kV lines

Configuration	Proposed A-3				Existing A-3	
ROW width, ft.	300				150	
Line	Sickler-Schultz 500-kV		Rocky Reach-Maple Valley 345-kV		Rocky Reach-Maple Valley 345-kV	
Clearance	min.	avg.	min.	avg.	min.	avg.
Peak field, kV/m	8.5	4.7	5.4	3.1	5.2	2.9
Edge of ROW, kV/m	1.9	1.9	2.1	1.9	2.0	1.8

Table 3, continued

d) Configuration A-4: Schultz-Hanford/Wautoma 500-kV line and six existing lines east of Schultz Substation

Configuration	**Proposed A-4**									
ROW width, ft.	637.5									
Line	Grand Coulee-Schultz DC 500-kV		Columbia-Ellensburg 115-kV		Covington-Columbia #3/ Olympia-Grand Coulee 230-/287-kV DC		Vantage-Schultz 500-kV		Schultz-Hanford/ Wautoma 500-kV	
Clearance	min	avg.	min	Avg.	min.	avg.	min	avg.	min	avg.
Peak field, kV/m	9.7	5.9	1.7	1.0	2.9/3.2	1.8/1.8	8.6	4.6	8.8	4.9
Edge of Row, kV/m	2.1	2.1	—	—	—	—	—	—	2.0	2.0

Configuration	**Existing A-4**									
ROW width, ft.	637.5									
Line	Grand Coulee-Schultz 500-kV DC		Columbia-Ellensburg 115-kV		Covington-Columbia #3/ Olympia-Grand Coulee 230-/287-kV DC		Sickler-Schultz 500-kV		Vantage-Schultz 500-kV	
Clearance	min	avg.	min	avg.	min	avg.	min.	Avg.	min	avg.
Peak field, kV/m	9.7	5.9	1.7	1.0	2.9/3.2	1.8/1.8	8.5	4.5	8.4	5.1
Edge of Row, kV/m	2.1	2.1	—	—	—	—	—	—	5.2	4.0

Table 3, continued

e) Configuration D-1: Schultz-Wautoma 500-kV and Vantage-Midway 230-kV lines

Configuration	**Proposed D-1**				**Existing D-1**	
ROW width, ft.	250				100	
Line	Vantage-Midway 230-kV		Schultz-Wautoma 500-kV		Vantage-Midway 230-kV	
Clearance	min.	avg.	min.	avg.	min.	avg.
Peak field, kV/m	3.3	2.0	8.9	5.0	3.1	1.8
Edge of ROW, kV/m	2.2	1.7	2.0	2.0	2.0	1.5

Table 3, continued

f) Configuration D-2: Schultz-Wautoma 500-kV and four existing parallel lines south of Midway Substation

Segment-Configuration	**Proposed D-2**									
ROW width, ft.	575									
Line	N. Bonneville-Midway 230-kV		Midway-Moxee 115-kV		Midway-Grandview 115-kV		Big Eddy-Midway 230-kV		Schultz-Wautoma 500-kV	
Clearance	min.	avg.	min.	avg.	min.	avg.	min.	avg.	min.	avg.
Peak field, kV/m	3.2	1.9	0.9	0.4	0.9	0.4	3.2	1.9	8.9	5.0
Edge of ROW, kV/m	0.1	0.1	—	—	—	—	—	—	2.0	2.0

Segment-Configuration	**Existing D-2**							
ROW width, ft.	487.5							
Line	N. Bonneville-Midway 230-kV		Midway-Moxee 115-kV		Midway-Grandview 115-kV		Big Eddy-Midway 230-kV	
Clearance	min.	avg.	min.	avg.	Min.	avg.	min.	avg.
Peak field, kV/m	3.2	1.9	0.8	0.4	1.0	0.4	3.3	1.9
Edge of ROW, kV/m	0.1	0.1	—	—	—	—	1.4	1.2

Table 3, continued

g) Configuration D-3: Schultz-Wautoma 500-kV and three existing parallel lines south of Midway Substation

Segment-Configuration	**Proposed D-3**							
ROW width, ft.	525							
Line Description	N. Bonneville - Midway 230-kV		Midway-Grandview 115-kV		Big Eddy-Midway 230-kV		Schultz-Wautoma 500-kV	
Clearance	min.	avg.	Min.	avg.	min.	avg.	min.	Avg.
Peak field, kV/m	3.2	1.9	0.9	0.4	3.2	1.8	8.9	5.0
Edge of ROW, kV/m	0.1	0.1	—	—	—	—	2.0	2.0

Segment-Configuration	**Existing D-3**					
ROW width, ft.	437.5					
Line Description	N. Bonneville - Midway 230-kV		Midway-Grandview 115-kV		Big Eddy-Midway 230-kV	
Clearance	min.	avg.	min.	avg.	min.	avg.
Peak field, kV/m	3.2	1.9	1.0	0.4	3.3	1.9
Edge of ROW, kV/m	0.1	0.1	—	—	1.4	1.2

Table 3, continued

h) Configuration D-4: Schultz-Wautoma 500-kV and Midway-Big Eddy 230-kV lines.

Segment-Configuration	**Proposed D-4**				**Existing D-4**	
ROW width, ft.	275				125	
Line	Midway-Big Eddy 230-kV		Schultz-Wautoma 500-kV		Midway-Big Eddy 230-kV	
Clearance	min.	avg.	min.	avg.	min.	avg.
Peak field, kV/m	3.4	2.0	8.9	4.9	3.2	1.9
Edge of ROW, kV/m	1.5	1.3	2.0	2.0	1.3	1.2

Table 4: Calculated magnetic fields for configurations of the proposed Schultz–Hanford/Wautoma 500-kV line operated at maximum current. Configurations are described in Tables 1 and 2. (4 pages)

a) Configuration A-1: Schultz–Hanford 500-kV line only

Configuration	Proposed A-1		Existing	
ROW width, ft.	150		—	
Line	Schultz–Hanford/Wautoma 500-kV		—	
Clearance	Min.	avg.	—	—
Peak field, mG	244	137	—	—
Edge of ROW, mG	55	46	—	—

b) Configuration A-2: Realigned Sickler-Schultz - 500-kV line only

Configuration	Proposed A-2		Existing	
ROW width, ft.	150		—	
Line	Sickler-Schultz 500-kV		—	
Clearance	min.	avg.	—	—
Peak field, mG	262	145	—	—
Edge of ROW, mG	57	48	—	—

c) Configuration A-3: Realigned Sickler-Schultz 500-kV and Rocky Reach-Maple Valley 345-kV lines

Configuration	Proposed A-3				Existing A-3	
ROW width, ft.	300				150	
Line	Sickler-Schultz 500-kV		Rocky Reach-Maple Valley 345-kV		Rocky Reach-Maple Valley 345-kV	
Clearance	min.	avg.	min.	avg.	min.	avg.
Peak field, mG	257	141	111	69	101	62
Edge of ROW, mG	60	50	40	33	35	28

Table 4, continued

d) Configuration A-4: Schultz-Hanford/Wautoma 500-kV line and six existing lines east of Schultz Substation

Configuration	**Proposed A-4**									
ROW width, ft.	637.5									
Line	Grand Coulee-Schultz DC 500-kV		Columbia-Ellensburg 115-kV		Covington-Columbia #3/ Olympia-Grand Coulee 230-/287-kV DC		Vantage-Schultz 500-kV		Schultz-Hanford/ Wautoma 500-kV	
Clearance	min	avg.	min	avg.	min.	avg.	min	Avg.	min	avg.
Peak field, mG	233	150	112	87	68	42	122	69	239	134
Edge of Row, mG	138	109	—	—	—	—	—	—	60	51

Configuration	**Existing A-4**									
ROW width, ft.	637.5									
Line	Grand Coulee-Schultz 500-kV DC		Columbia-Ellensburg 115-kV		Covington-Columbia #3/ Olympia-Grand Coulee 230-/287-kV DC		Sickler-Schultz 500-kV		Vantage-Schultz 500-kV	
Clearance	min.	avg.	min	avg.	min	avg.	min.	avg.	Min.	avg.
Peak field, mG	206	132	108	85	90	69	253	190	302	203
Edge of Row, mG	121	94	—	—	—	—	—	—	158	119

Table 4, continued

e) Configuration D-1: Schultz-Wautoma 500-kV and Vantage-Midway 230-kV lines

Configuration	**Proposed D-1**				**Existing D-1**	
ROW width, ft.	250				100	
Line	Vantage-Midway 230-kV		Schultz-Wautoma 500-kV		Vantage-Midway 230-kV	
Clearance	min.	avg.	min.	avg.	min.	avg.
Peak field, mG	139	89	239	132	133	84
Edge of ROW, mG	72	55	59	49	67	49

Table 4, continued

f) Configuration D-2: Schultz-Wautoma 500-kV and four existing parallel lines south of Midway Substation

Segment-Configuration	**Proposed D-2**									
ROW width, ft.	637.5									
Line	N. Bonneville-Midway 230-kV		Midway-Moxee 115-kV		Midway-Grandview 115-kV		Big Eddy-Midway 230-kV		Schultz-Wautoma 500-kV	
Clearance	min.	avg.	min.	avg.	min.	avg.	min.	avg.	min.	avg.
Peak field, mG	109	66	37	20	40	20	158	98	237	130
Edge of ROW, mG	7	7	—	—	—	—	—	—	60	50

Segment-Configuration	**Existing D-2**							
ROW width, ft.	487.5							
Line	N. Bonneville-Midway 230-kV		Midway-Moxee 115-kV		Midway-Grandview 115-kV		Big Eddy-Midway 230-kV	
Clearance	min.	avg.	min.	Avg.	min.	avg.	Min.	avg.
Peak field, mG	112	68	38	21	40	18	165	101
Edge of ROW, mG	7	7	—	—	—	—	62	50

Table 4, continued

g) Configuration D-3: Schultz-Wautoma 500-kV and three existing parallel lines south of Midway Substation

Segment-Configuration	**Proposed D-3**							
ROW width, ft.	587.5							
Line Description	N. Bonneville-Midway 230-kV		Midway-Grandview 115-kV		Big Eddy-Midway 230-kV		Schultz-Wautoma 500-kV	
Clearance	min.	avg.	min.	avg.	min.	avg.	Min.	avg.
Peak field, mG	108	66	58	35	157	97	237	130
Edge of ROW, mG	7	7	—	—	—	—	60	50

Segment-Configuration	**Existing D-3**					
ROW width, ft.	437.5					
Line Description	N. Bonneville-Midway 230-kV		Midway-Grandview 115-kV		Big Eddy-Midway 230-kV	
Clearance	min.	avg.	Min.	avg.	min.	avg.
Peak field, mG	111	67	58	33	165	101
Edge of ROW, mG	7	7	—	—	62	50

Table 4, continued

h) Configuration D-4: Schultz-Wautoma 500-kV and Midway-Big Eddy 230-kV lines.

Segment-Configuration	**Proposed D-4**				**Existing D-4**	
ROW width, ft.	275				125	
Line	Midway-Big Eddy 230-kV		Schultz-Wautoma 500-kV		Midway-Big Eddy 230-kV	
Clearance	min.	avg.	min.	avg.	min.	avg.
Peak field, mG	167	106	238	131	170	107
Edge of ROW, mG	60	50	59	49	59	47

Table 5: States with transmission-line field limits

STATE AGENCY	WITHIN RIGHT-OF-WAY	AT EDGE OF RIGHT-OF-WAY	COMMENTS
a. 60-Hz ELECTRIC FIELD LIMIT, kV/m			
Florida Department of Environmental Regulation	8 (230 kV) 10 (500 kV)	2	Codified regulation, adopted after a public rulemaking hearing in 1989.
Minnesota Environmental Quality Board	8	—	12-kV/m limit on the HVDC nominal electric field.
Montana Board of Natural Resources and Conservation	7[1]	1[2]	Codified regulation, adopted after a public rulemaking hearing in 1984.
New Jersey Department of Environmental Protection	—	3	Used only as a guideline for evaluating complaints.
New York State Public Service Commission	11.8 (7,11)[1]	1.6	Explicitly implemented in terms of a specified right-of-way width.
Oregon Facility Siting Council	9	—	Codified regulation, adopted after a public rulemaking hearing in 1980.
b. 60-Hz MAGNETIC FIELD LIMIT, mG			
Florida Department of Environmental Regulation	—	150 (230 kV) 200 (500 kV)	Codified regulations, adopted after a public rulemaking hearing in 1989.
New York State Public Service Commission	—	200	Adopted August 29, 1990.

1 At road crossings
2 Landowner may waive limit

Sources: TDHS Report, 1989;TDHS Report, 1990

Table 6: Common noise levels

Sound Level, dBA	Noise Source or Effect
128	Threshold of pain
108	Rock-and-roll band
80	Truck at 50 ft.
70	Gas lawnmower at 100 ft.
60	Normal conversation indoors
50	Moderate rainfall on foliage
50	Edge of proposed 500-kV right-of-way during rain
40	Refrigerator
25	Bedroom at night
0	Hearing threshold

Adapted from: USDOE, 1996.

Table 7: Typical sound attenuation (in decibels) provided by buildings

	Windows opened	Windows closed
Warm climate	12	24
Cold climate	17	24

Source: EPA, 1978.

Table 8: Predicted foul-weather audible noise (AN) levels at edge of right-of-way (ROW) for proposed Schultz–Hanford/Wautoma 500-kV line. AN levels expressed in decibels on the A-weighted scale (dBA). L_{50} and L_5 denote the levels exceeded 50 and 5 percent of the time, respectively. For the parallel-line configurations[1], the AN level at the edge of the proposed Schultz-Hanford Area Project ROW is given first.

	Foul-weather AN					
	Proposed			Existing		
Configuration[1]	ROW ft. (m)	L_{50}, dBA	L_5, dBA	ROW ft. (m)	L_{50}, dBA	L_5, dBA
A-1	150 (46)	50	54	—	—	—
A-2	150 (46)	59	63	—	—	—
A-3	300 (91)	59, 57	63, 61	150 (46)	54	57
A-4	637.5 (194)	57, 54	60, 57	637.5 (194)	65, 57	69, 61
D-1	250 (76)	50, 48	53, 52	100 (30)	44	47
D-2	637.5 (194)	50, 42	53, 46	487.5 (149)	39, 37	42, 41
D-3	587.5 (179)	50, 42	53, 46	437.5 (133)	39, 37	43, 41
D-4	275 (84)	50, 46	53, 49	125 (38)	37	40

1 Configurations are described in Tables 1 and 2.

Table 9: Predicted fair-weather radio interference (RI) levels at 100 feet (30.5 m) from the outside conductor of the proposed Schultz–Hanford/Wautoma 500-kV line. RI levels given in decibels above 1 microvolt/meter (dBµV/m) at 1.0 MHz. L_{50} denotes level exceeded 50 percent of the time. For the parallel-line configurations the RI level on the side of the proposed Schultz-Hanford Area ROW is given first.

	Fair-weather RI	
	Proposed	**Existing**
Configuration[1]	**L_{50}, dBµV/m**	**L_{50}, dBµV/m**
A-1	40	—
A-2	47	—
A-3	47, 39	39
A-4	40, 38	47, 38
D-1	39, 31	31
D-2	39, 28	22, 28
D-3	39, 28	22, 28
D-4	39, 30	22

1 Configurations are described in Tables 1 and 2.

Table 10: Predicted maximum foul-weather television interference (TVI) levels predicted at 100 feet (30.5 m) from the outside conductor of the proposed Schultz–Hanford/Wautoma 500-kV line. TVI levels given in decibels above 1 microvolt/meter (dBμV/m) at 75 MHz. For the parallel-line configurations, the TVI level on the side of the proposed Schultz-Hanford Area ROW is given first.

	Foul-weather TVI	
	Proposed	Existing
Configuration[1]	Maximum (foul), dBμV/m	Maximum (foul), dBμV/m
A-1	26	-
A-2	33	-
A-3	33, 26	26
A-4	26, 19	33, 19
D-1	25, 17	18
D-2	25, 15	9, 15
D-3	25, 15	9, 15
D-4	25, 11	9

1 Configurations are described in detail in Tables 1 and 2.

Figure 1: Configurations for proposed Schultz-Hanford Area Project 500-kV line: a) Proposed line with no parallel lines (Configuration A-1); b) Realigned Sickler-Schultz 500-kV with no parallel lines (Configuration A-2); c) Realigned Sickler-Schultz 500-kV line with parallel 345-kV line (Configuration A-3); d) Schultz-Hanford/Wautoma 500-kV line with six parallel lines east of Schultz Substation(Configuration A-4); e) Proposed Schultz – Wautoma 500-kV line with parallel Vantage – Midway 230-kV line (Configuration D-1); f) Proposed Schultz-Wautoma 500-kV line with four parallel existing lines south of Midway Substation (Configuration D-2); g) Proposed Schultz-Wautoma 500-kV line with three parallel existing lines south of Midway Substation (Configuration D-3); and h) Proposed Schultz-Wautoma 500-kV line with parallel Midway-Big Eddy 230-kV line (Configuration D-4). (8 pages)

a) Proposed line with no parallel lines (Configuration A-1) (not to scale)

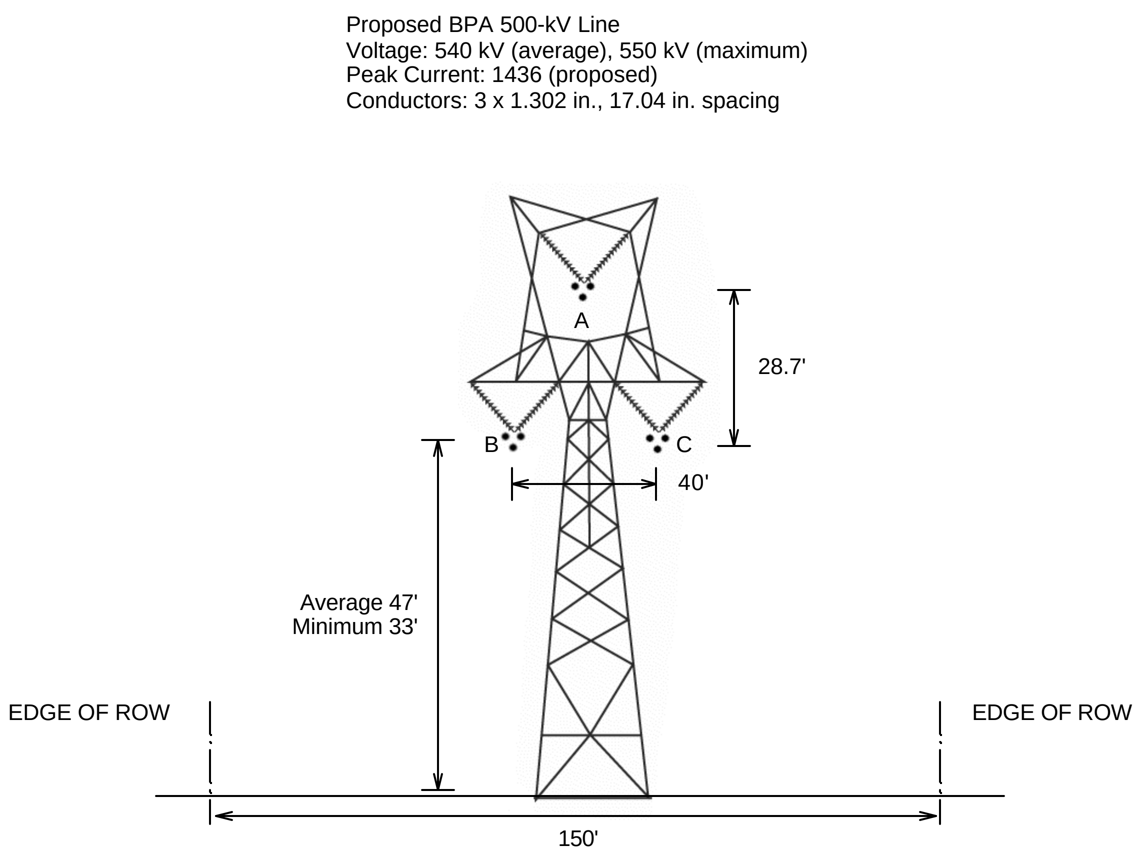


Figure 1, continued

b) Realigned Sickler-Schultz 500-kV line with no parallel lines (Configuration A-2) (not to scale)

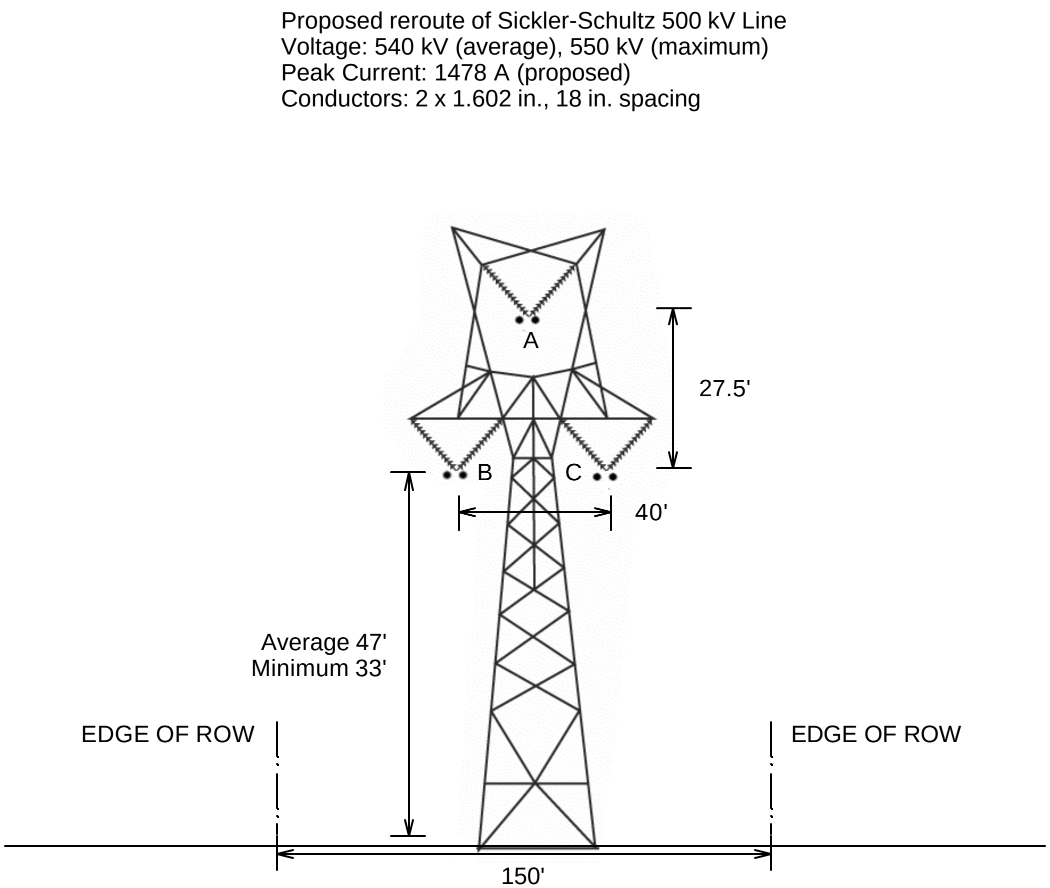


Figure 1, continued

c) Realigned Sickler-Schultz 500-kV line with parallel Rocky Reach-Maple Valley 345-kV line (Configuration A-3) (not to scale)

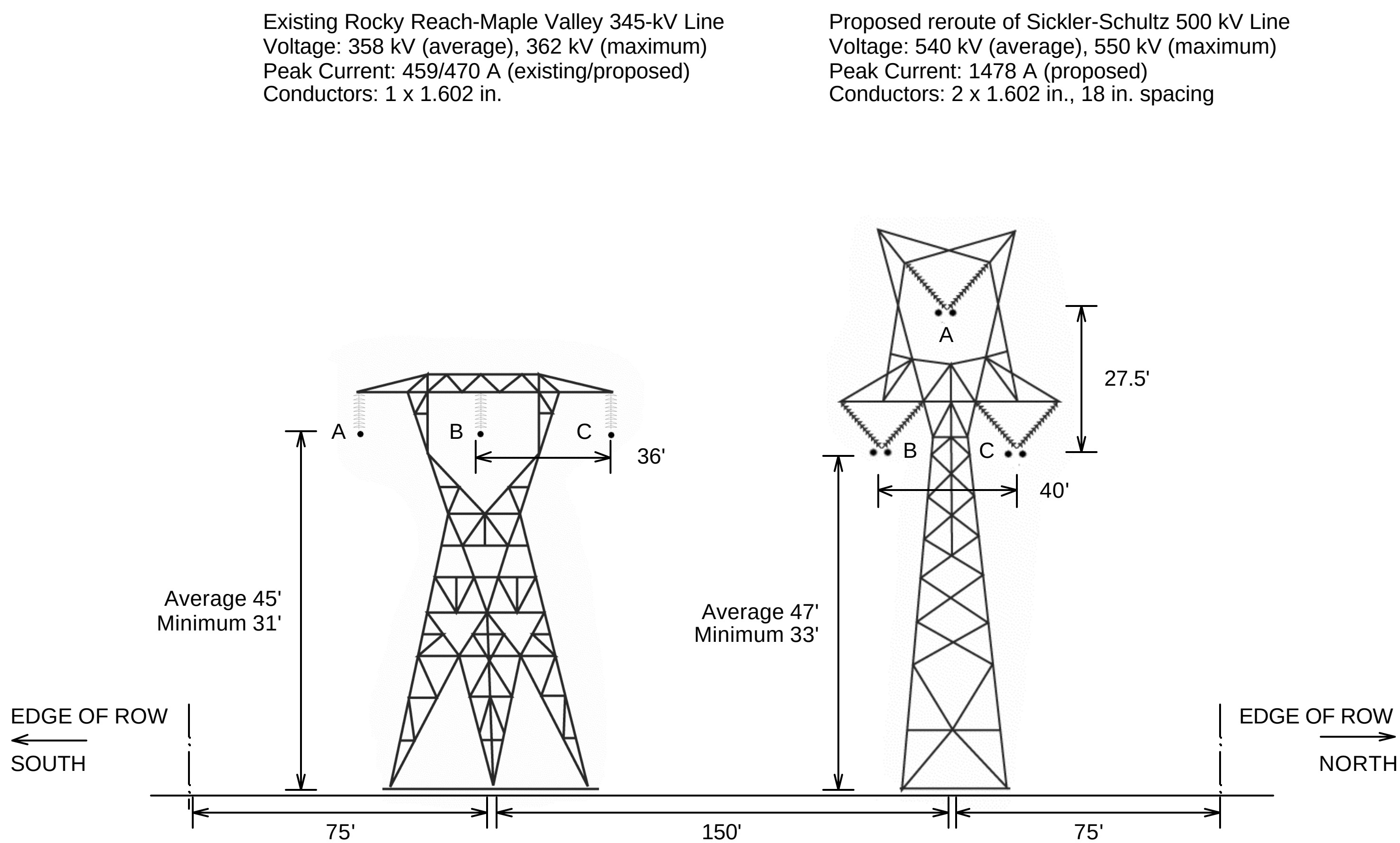


Figure 1, continued

d) Schultz-Hanford/Wautoma 500-kV line with six parallel lines east of Schultz Substation(Configuration A-4) (not to scale)

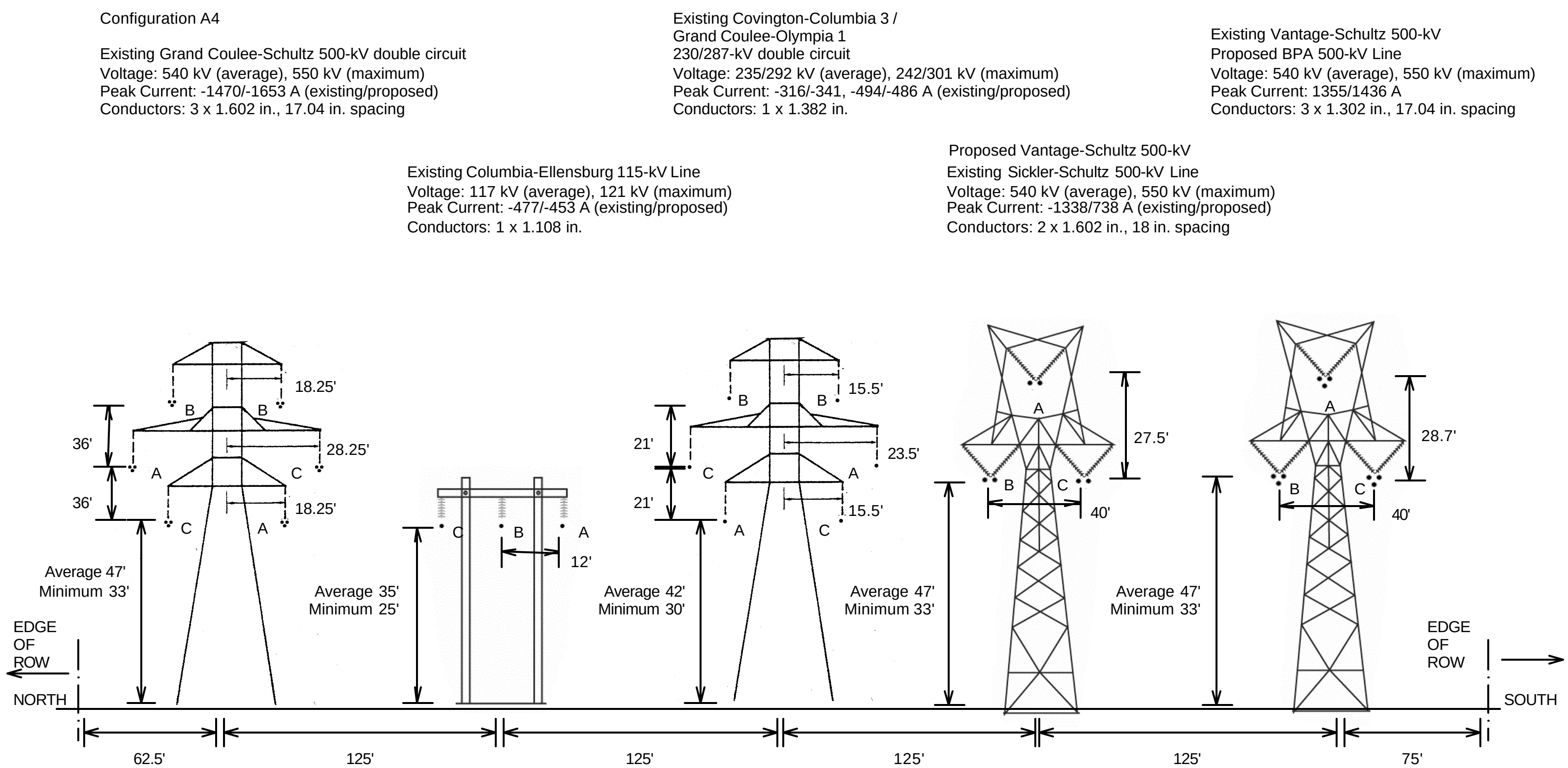


Figure 1, continued

e) Proposed Schultz – Wautoma 500-kV line with parallel Vantage – Midway 230-kV line (Configuration D-1). (Not to scale)

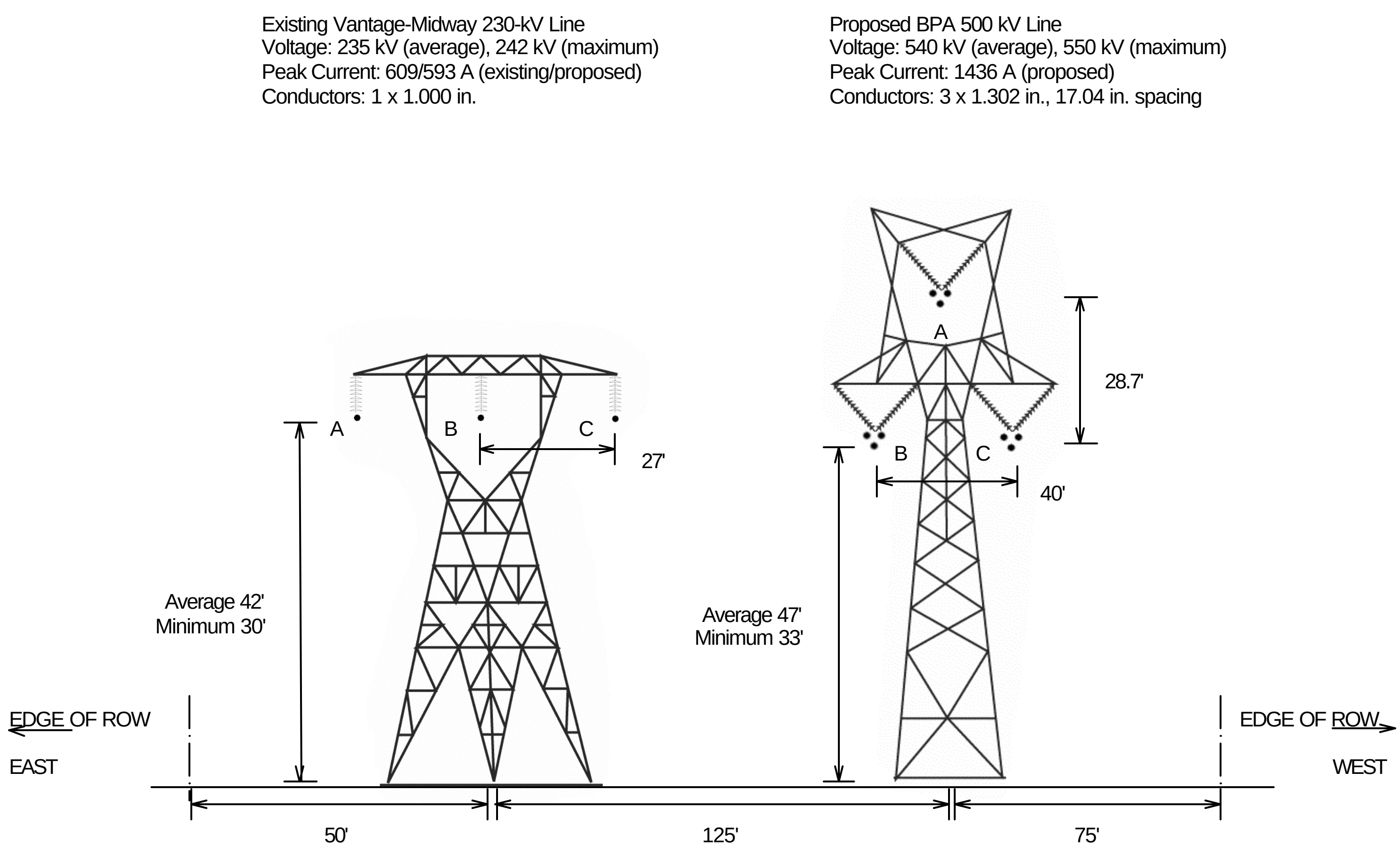


Figure 1, continued

f) Proposed Schultz-Wautoma 500-kV line with four parallel existing lines south of Midway Substation (Configuration D-2) (not to scale)

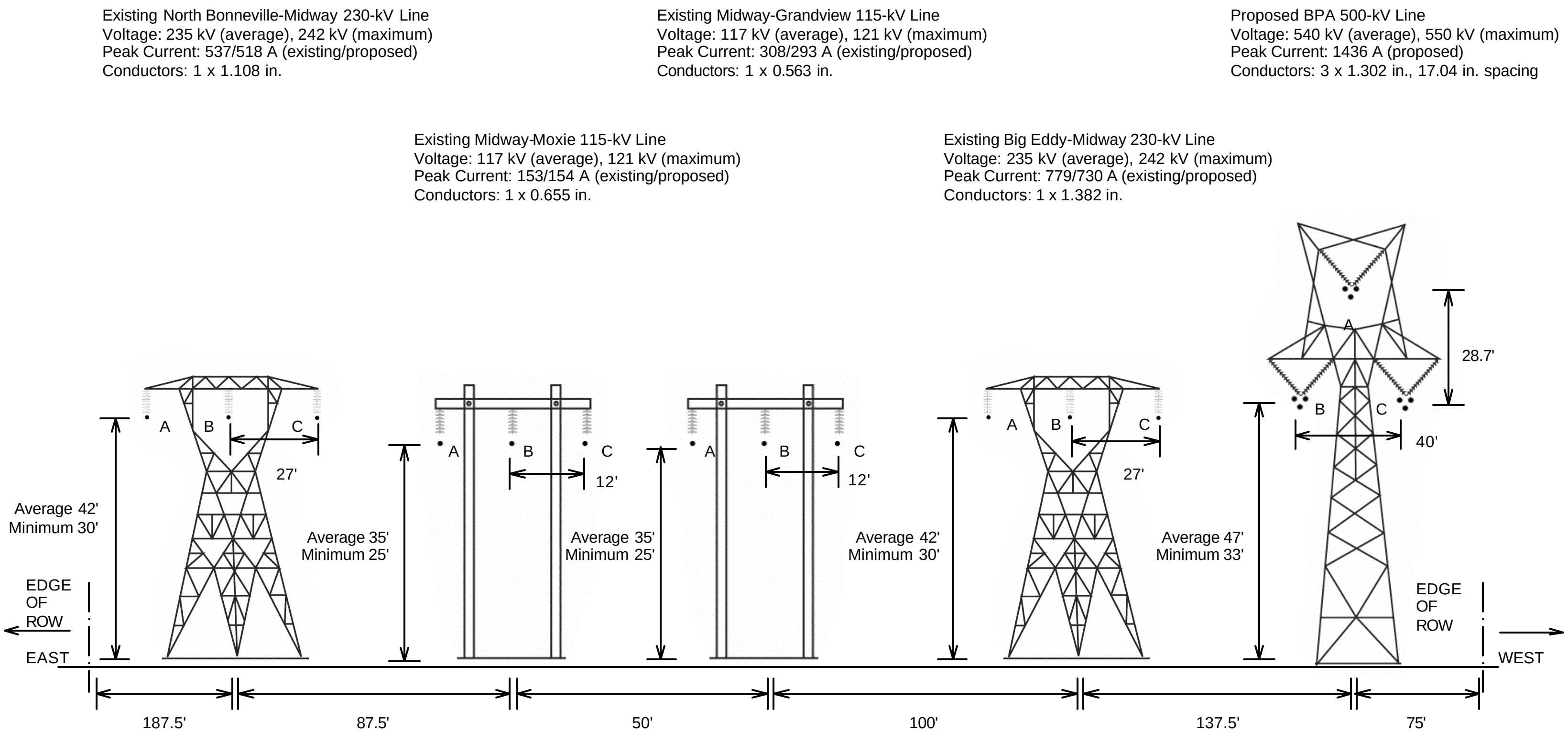


Figure 1, continued

g) Proposed Schultz-Wautoma 500-kV line with three parallel existing lines south of Midway Substation (Configuration D-3) (not to scale)

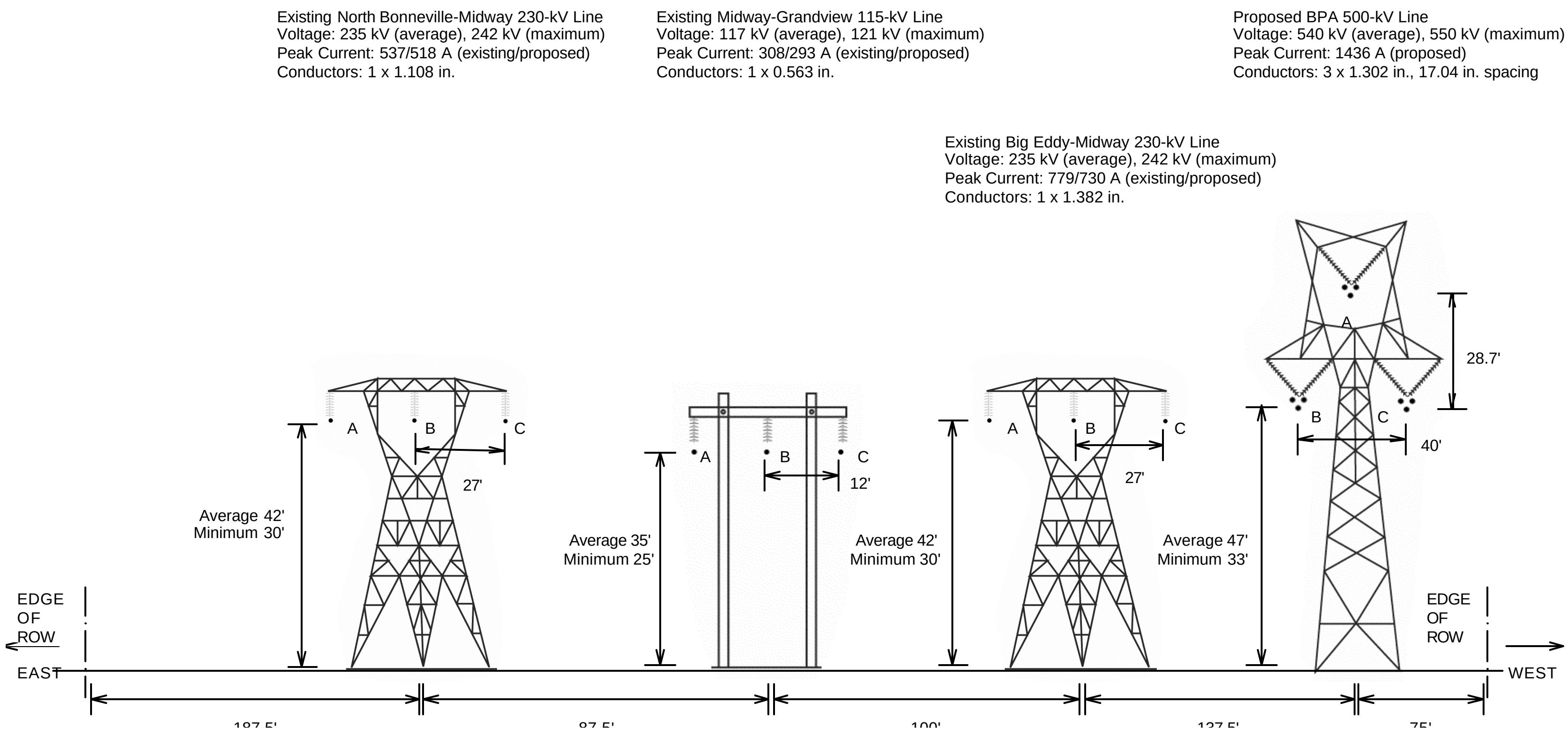


Figure 1, continued

h) Proposed Schultz-Wautoma 500-kV line with parallel Midway-Big Eddy 230-kV line (Configuration D-4) (not to scale)

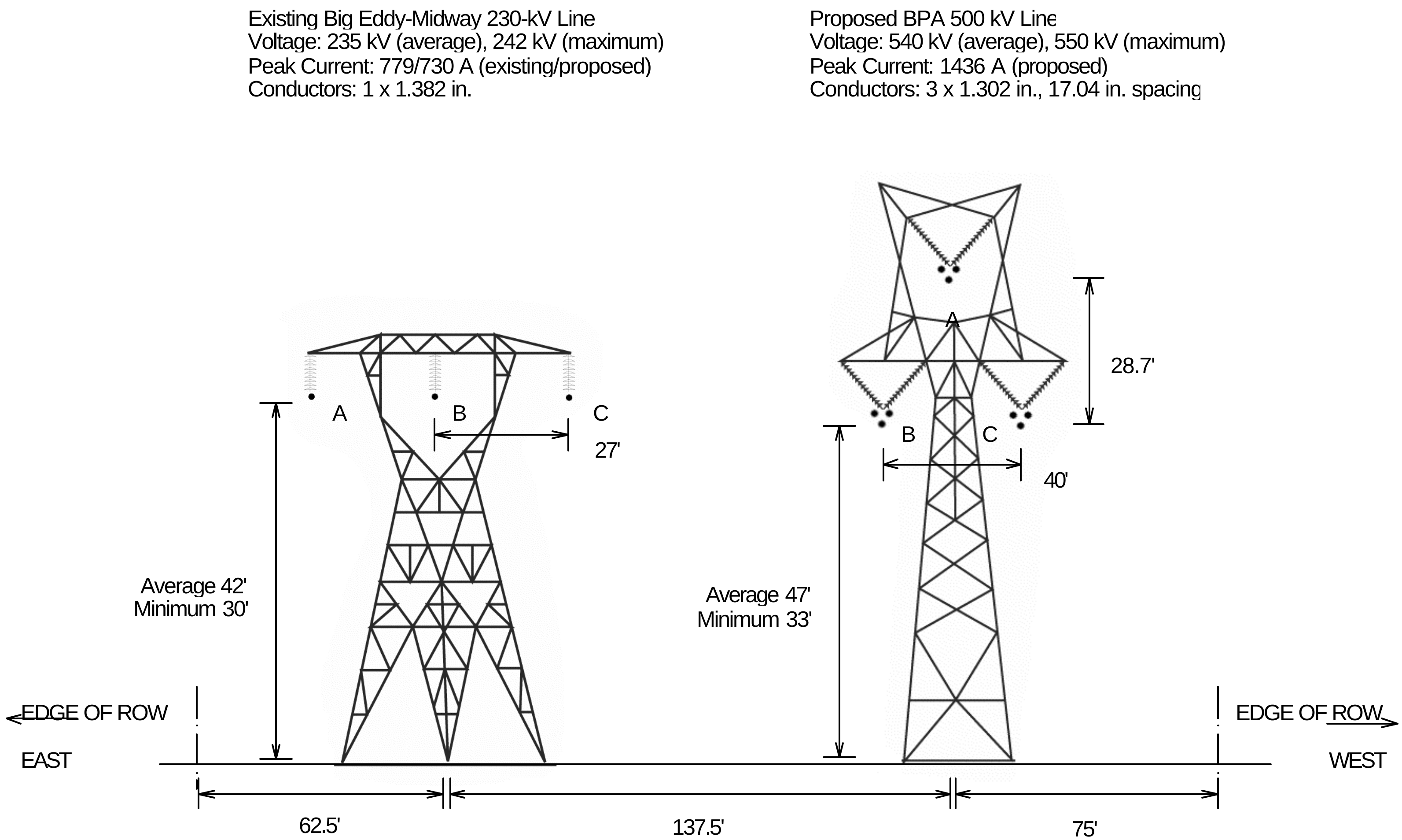


Figure 2: Electric-field profiles for selected configurations of proposed Schultz–Hanford/Wautoma 500-kV line: a) Proposed line with no parallel line (Configuration A-1); b) proposed line with parallel 230-kV line (Configuration D-1); c) proposed line with parallel 115-kV and 230-kV lines (Configuration D-3). Fields for maximum voltage and minimum clearances are shown. (2 pages)

a) Proposed line with no parallel line (Configuration A-1).

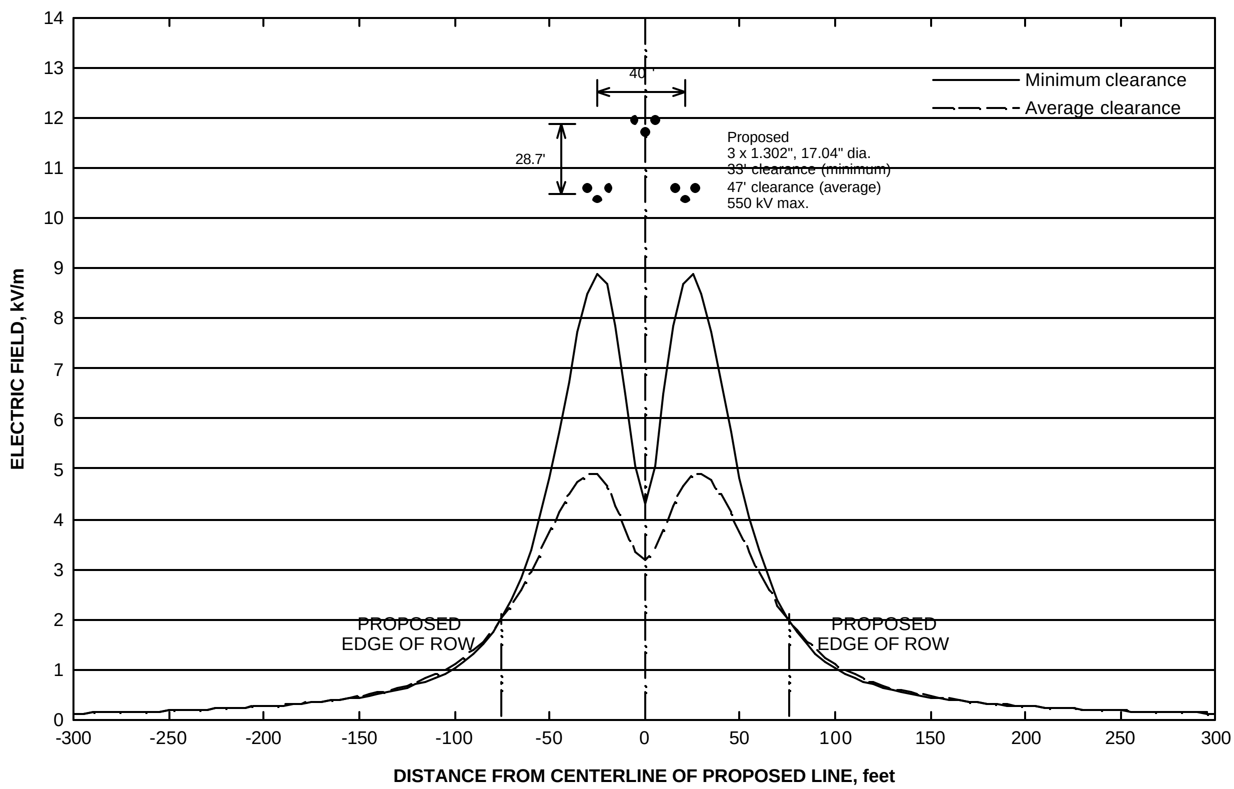
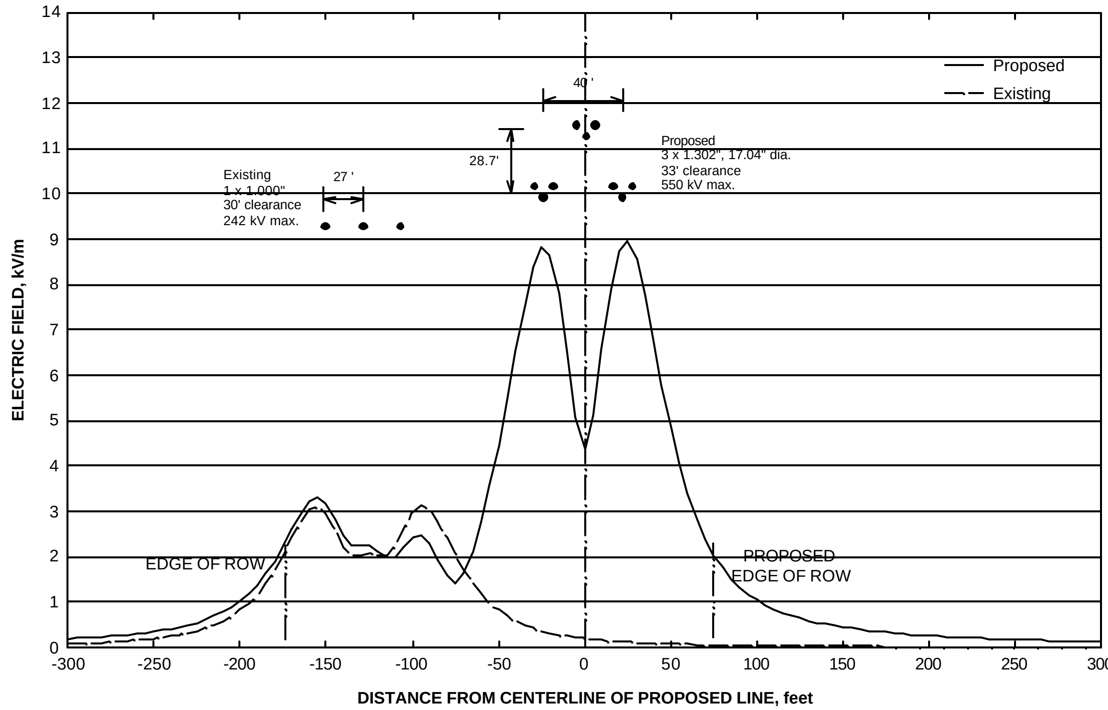


Figure 2, continued

b) Proposed line with parallel 230-kV line (Configuration D-1)



c) Proposed line with parallel 115-kV and 230-kV lines (Configuration D-3)

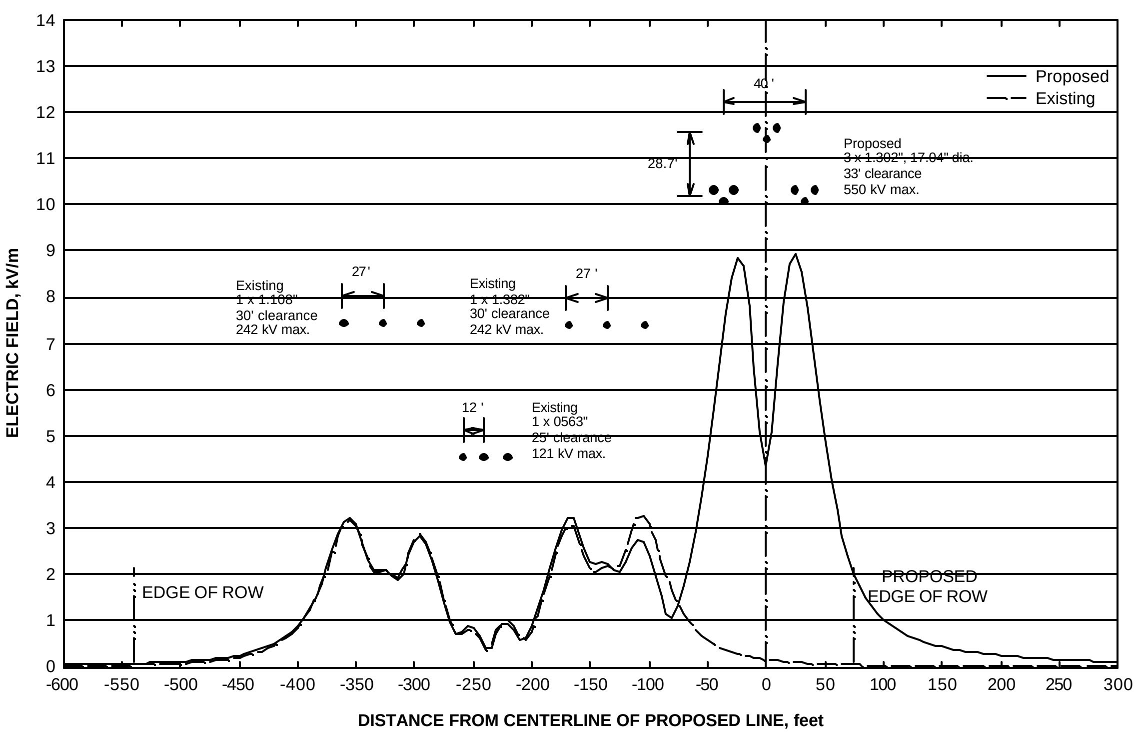


Figure 3: Magnetic-field profiles for selected configurations of the proposed Schultz–Hanford/Wautoma 500-kV line under maximum current conditions: a) proposed line with no parallel line (Configuration A-1); b) proposed line with parallel 230-kV line (Configuration D-1); and c) proposed line with parallel 115-kV and 230-kV lines (Configuration D-3). (2 pages)

a) Proposed line with no parallel line (Configuration A-1)

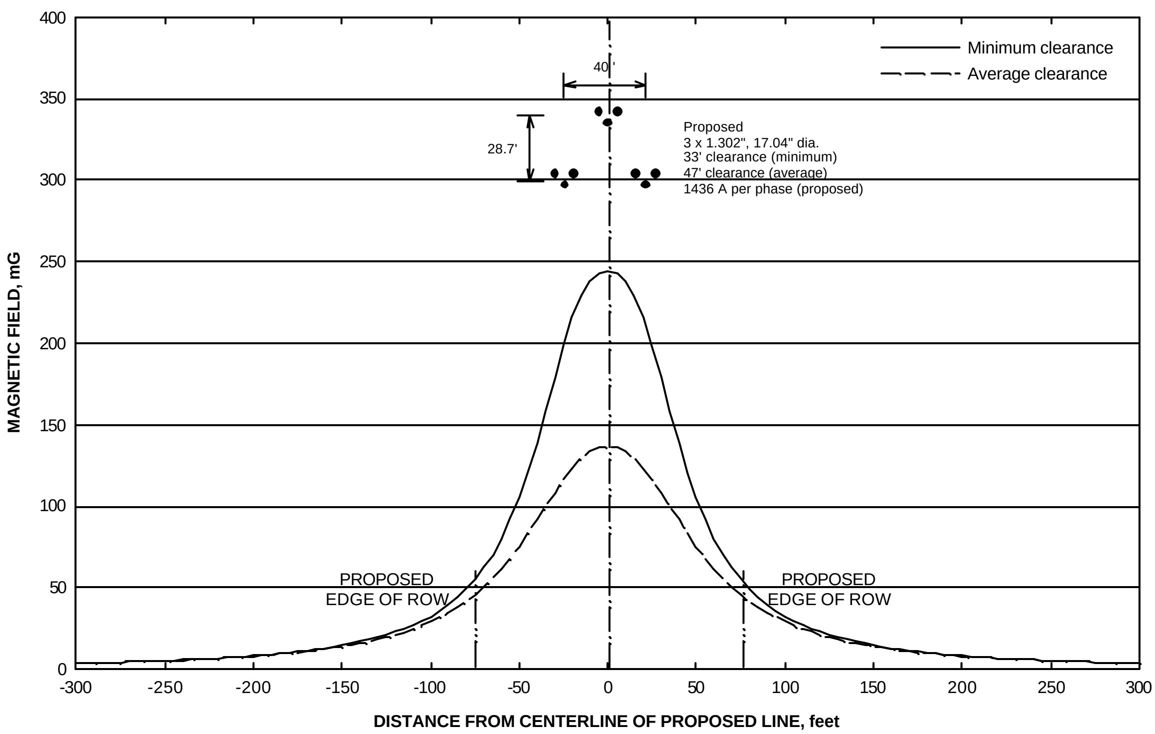
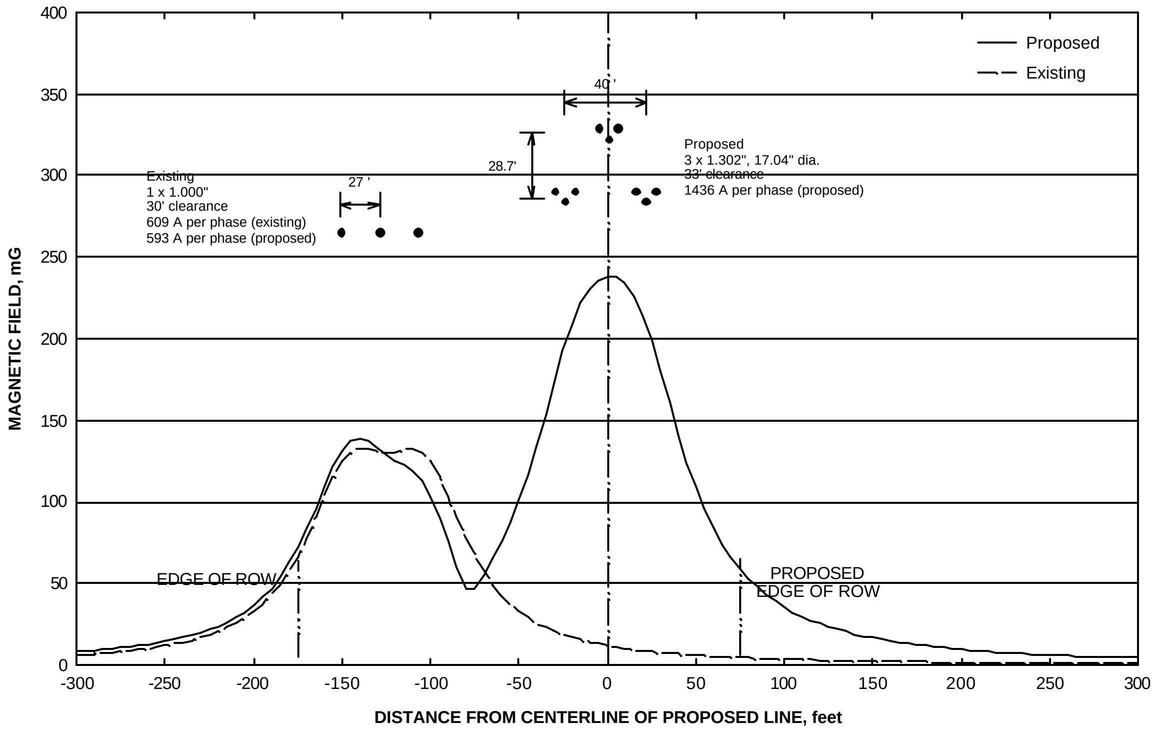


Figure 3, continued

b) Proposed line with parallel 230-kV line (Configuration D-1).



c) Proposed line with parallel 115-kV and 230 kV lines (Configuration D-3)

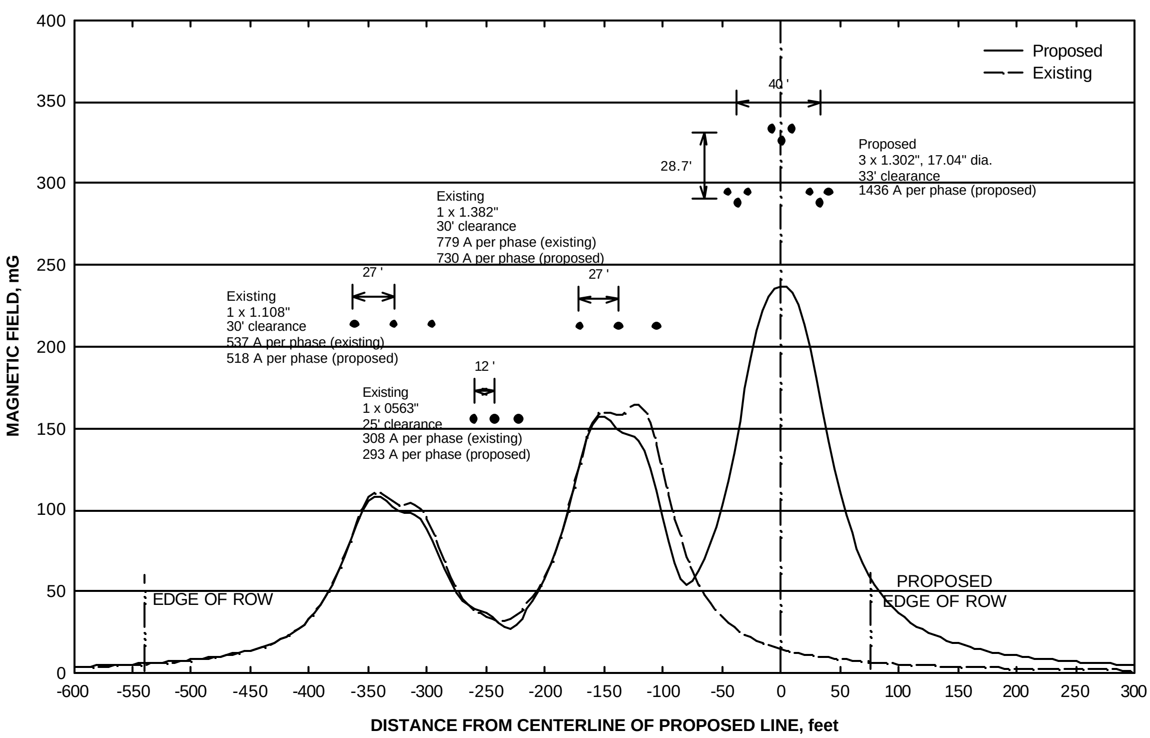


Figure 4: Predicted foul-weather L_{50} audible noise levels from selected configurations of proposed Schultz–Hanford/Wautoma 500-kV line a) proposed line with no parallel line (Configuration A-1); b) proposed line with parallel 230-kV line (Configuration D-1); and c) proposed line with parallel 115-kV and 230-kV lines (Configuration D-3). (2 pages)

a) Proposed line with no parallel line (Configuration A-1).

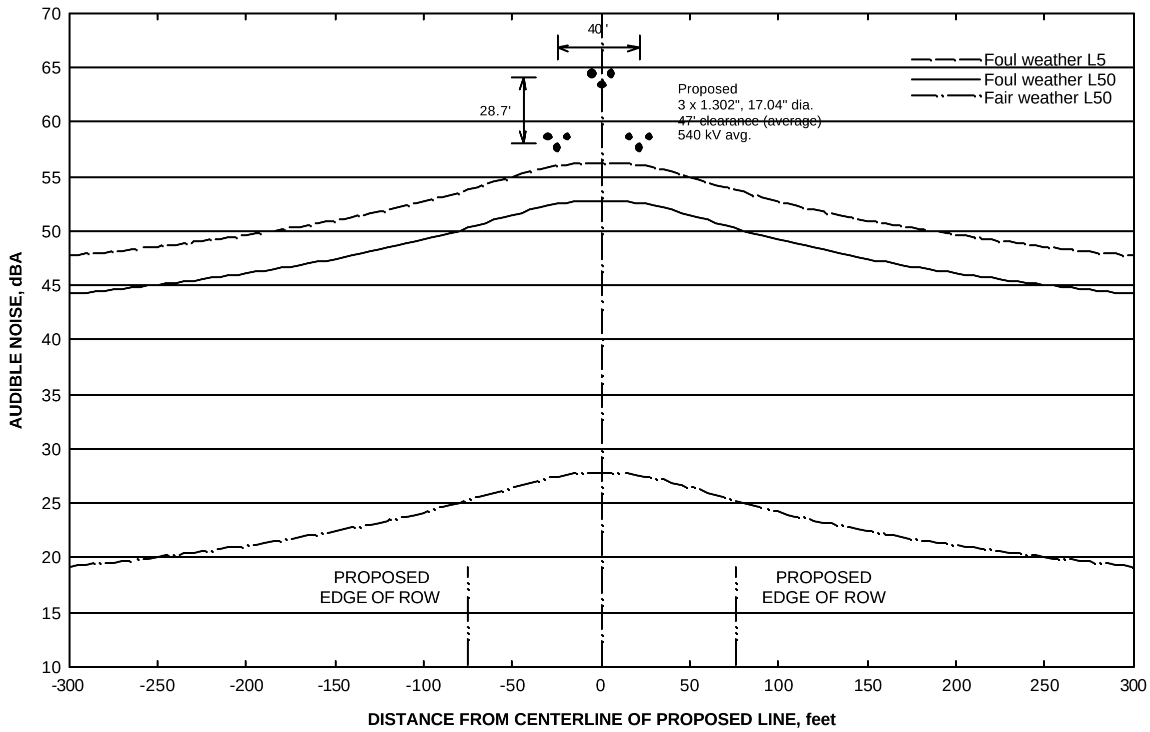
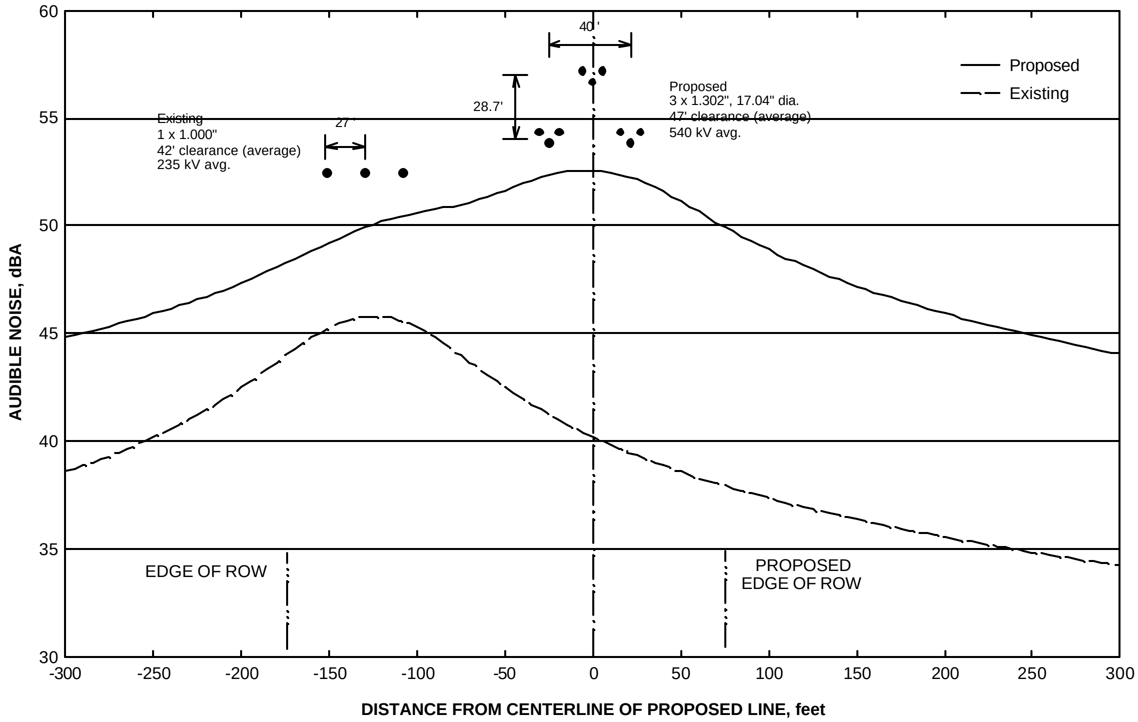


Figure 4, continued

b) Proposed line with parallel 230-kV line (Configuration D-1).



c) Proposed line with parallel 115-kV and 230-kV lines (Configuration D-3).